THE DUHAMEL REEF, ALBERTA.

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ABSTRACT

The Duhamel oil-field, central Alberta, (Twp. 45, Rge. 21, W. 4 Mer.) produces from these Upper Devonian reef sections. Photographs of 34 acetate peels of the carbonate section in Socony Duhamel 29-14 well, between 4410 and 4870 feet drilling depths, illustrate reefoid facies in the Upper Devonian Nisku and Leduc Formations. Thin section studies also include the overlying Calmar Shale, and the Ireton Shale separating the reefs.

The Calmar Shale is dark-greenish grey, calcareous, irregularly laminated, with pockets and stringers of pyrite.

The Nisku Dolomite is secondary. Algae and Amphipora indicate that deposition took place in warm, shallow, quiet marine water conditions. Anhydrite fills the vugs in the lower portion of the Nisku Formation. Porosity and permeability is relatively poor as compared to the underlying Leduc carbonates. X-ray diffraction indicates very high percentage of dolomite in the Nisku.

The Ireton Formation above the Leduc bioherm is greenish grey, fine grained dolomitic shale.

The Leduc reef is composed of light grey to yellowish grey bioclastic calcarenite and calcirudite. X-ray diffraction indicates no dolomite, though recrystallization has taken place and destroyed some of the internal structures of the organisms. Abundance of stromatoporoids, tabulate corals and algae suggest well aerated, highly agitated marine environment with normal salinity. Good intergranular and vuggy porosity is found throughout the reef.

Strontium content of the Leduc, determined by X-ray fluorescence method indicates a fore-reef location for the well. Strontium decreases with depth and intensity of recrystallization.

Well developed crystals of sphalerite in the Leduc Formation occur in vugs along with secondary calcite crystals. Chemical analysis reveals that the sphalerite was formed at low temperature. Presence of iron, cadmium and copper is detected by X-ray fluorescence technique.

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INTRODUCTION

General Statement

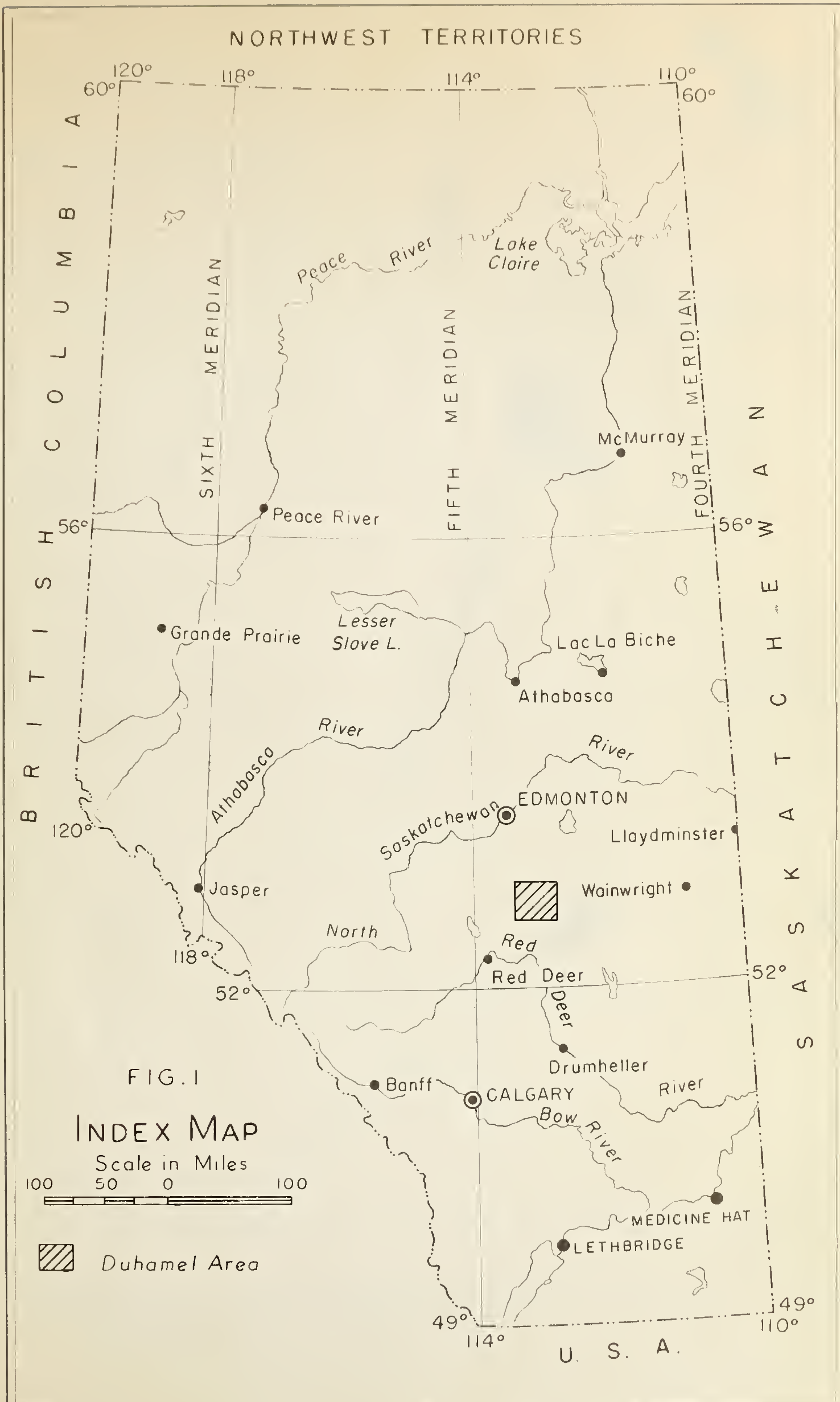
Dolomitization of carbonates has long been a controversial topic in geology. The discovery of oil in the Devonian carbonates of Alberta, in both dolomitic and non-dolomitic reefs, has given numerous fresh samples of both phases from the subsurface, unaltered by weathering effects.

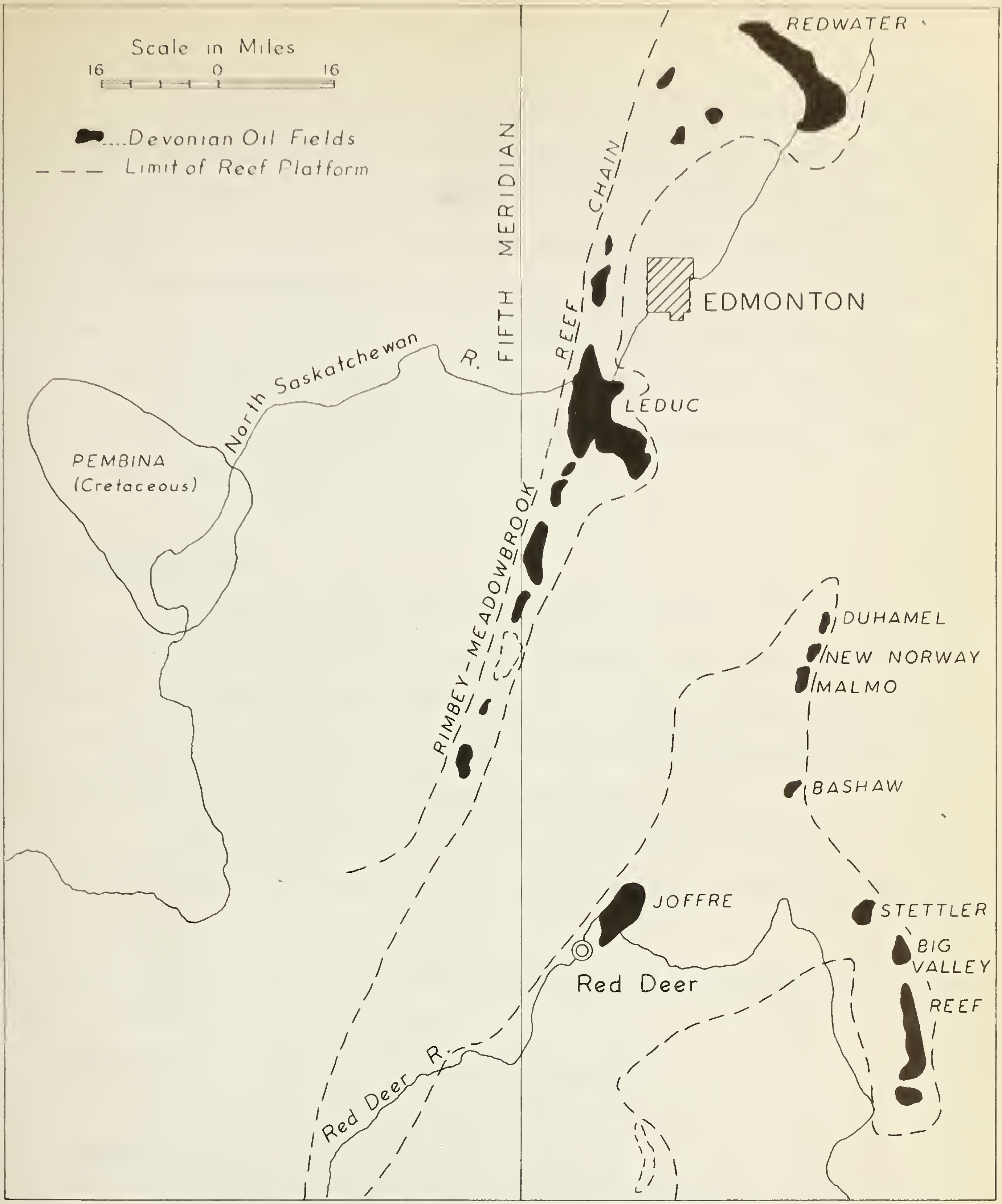
In Socony Duhamel 29-14 well in Central Alberta both dolomitic and non-dolomitic carbonates are encountered: the completely dolomitized Nisku Formation and the un-dolomitized Leduc Formation. Therefore with approximately the same post-Devonian history and a similar present depth of burial an excellent opportunity is provided to make a comparative study of these two kinds of carbonates and investigate the dolomitization question.

Location

In this study the writer examined samples from the Socony Duhamel 29-14 well in Lsd. 14, Sec. 29, Twp. 45, Rge. 21, W. 4 Mer., Alberta, Canada. This well was drilled by Socony Vacuum Exploration Company (now Mobil Oil of Canada Ltd.) in 1950. Drilling started on June 7, 1950 and was completed by December 28, in the same year, at a depth of 4870 feet. Coring commenced in Calmar Formation at a depth of 4400 feet. Nisku Formation was penetrated at 4411 feet; the Ireton Shale was encountered at 4565 feet and the Leduc Limestone at 4701 feet. These formations can be picked on the radioactivity log (Figure 3).

Both Nisku (D_2) and Leduc (D_3) Formations are productive in this well which lies at the north end of the Duhamel field (see Figure 4).


NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
U. S. A.
120°
118°
114°
110°
60°
56°
52°
49°
SIXTH MERIDIAN
FIFTH MERIDIAN
FOURTH MERIDIAN
Peace River
Lake Claire
McMurray
Peace River
Grande Prairie
Lesser Slave L.
Lac La Biche
Athabasca
Athabasca River
River
Saskatchewan
EDMONTON
Lloydminster
Jasper
Wainwright
North
Red
Red Deer
Deer
Drumheller
River
Banff
CALGARY
Bow River
MEDICINE HAT
LETHBRIDGE
FIG. I
INDEX MAP
Scale in Miles
100 50 0 100
Duhamel Area



(Modified after Andrichuk, 1958)

Fig. 2 Index map of central Alberta showing location of Duhamel Reef in relation to the major Devonian oil fields of Alberta.

The Duhamel field is located at the north end of the Malmo-New Norway-Duhamel reefal trend which is north-northeast of the Bashaw-Joffre reef complex. To the northwest it is paralleled by the Rimbey-Meadowbrook chain (Westerose-Bonnie Glen-Wizard Lake-Glen Park-Leduc-Woodbend reefs); on the southeast are the Erskine and Stettler-Big Valley reefs. Redwater oil field is situated almost due north of the Duhamel reef (Figure 2). It is thus situated between two major oil producing reef chains. Minor accumulations of oil have been found in the Bashaw reef. Considerable oil has been found in the Malmo-New Norway-Duhamel trend of reefs.

Purpose of Study

The purpose of this study was to make a detailed biofacies and lithofacies analysis of the Duhamel reef as encountered in the Socony Duhamel 29-14 well. An attempt was made to establish a lithologic and faunal relationship within the reefs. In light of the data thus obtained, a comparative study of the Nisku biostrome and Leduc bioherm was carried out.

Some of the outstanding features of the Duhamel reef are:

(a) The complete dolomitization of the Nisku Formation and the paucity of fauna in it.

(b) The undolomitized nature of the Leduc bioherm and the evidence of prolific frame-building organisms in it.

(c) Occurrence of sphalerite in the Leduc Formation.

Method of Study

Polished sections of a number of cores from the well were prepared to give a representative picture of the reef. Acetate peels were made of the Nisku and Leduc samples. The description of the plates from 34 critical samples form

Radioactivity Log

SOCONY DUHAMEL NO. 29-14

DUHAMEL FIELD

L.S.D 14-29-45-21 W4

ELEV. 2470′

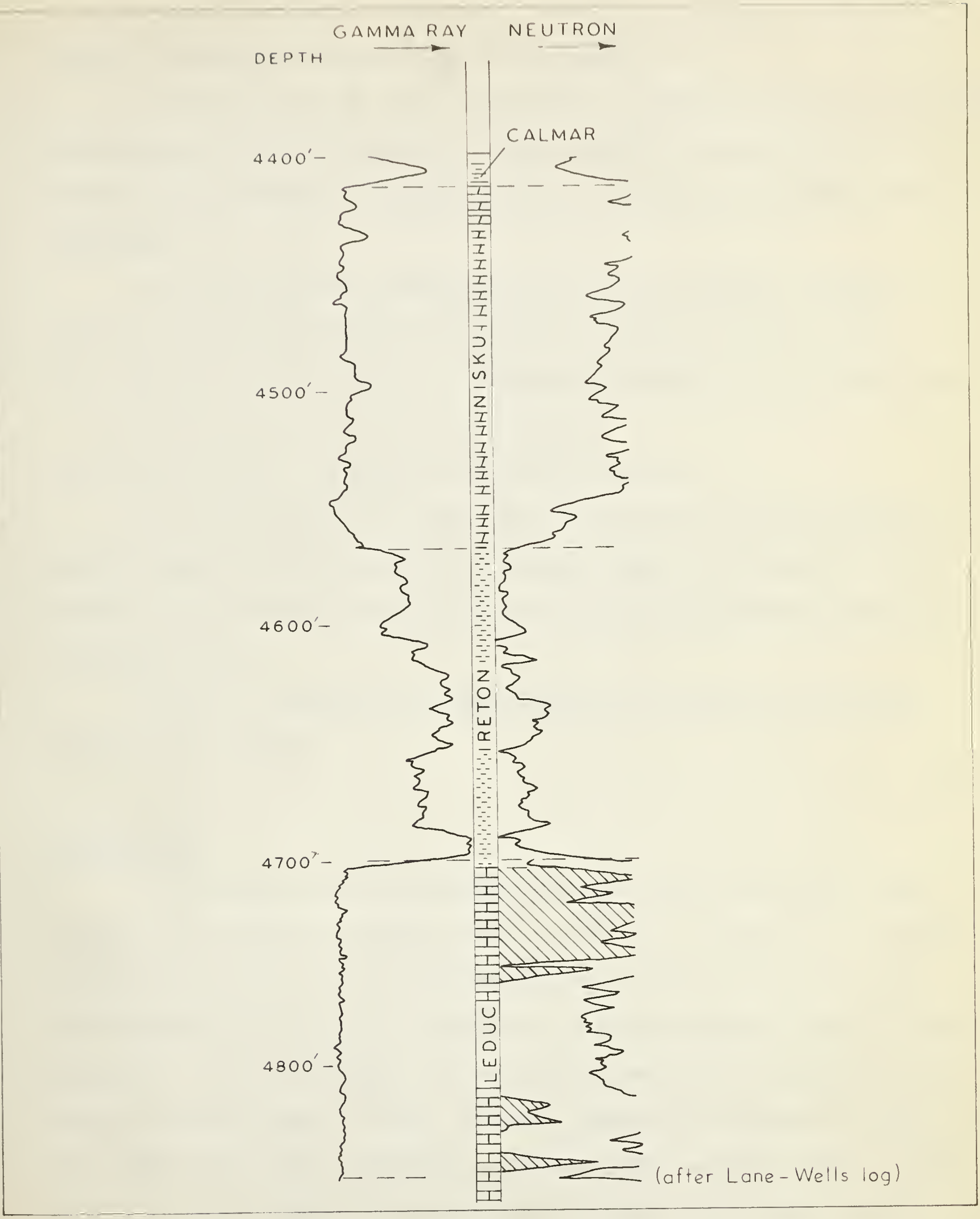


FIG. 3

a major part of the study. Acetate-peel method gives excellent results and greatly facilitates the description of the formations.

A study of thin sections further helps to understand the finer structures and textures of the reef sediments. It also gives and insight into the diagenesis of the sediments. Insoluble residue and heavy mineral studies were also undertaken.

The following X-ray techniques were used for geochemical analysis:

(a) X-ray diffraction technique to determine the dolomite-calcite ratios.

(b) X-ray fluorescence technique to determine the variation of strontium content in the fossils found in the Leduc Formation.

(c) X-ray diffraction technique for sphalerite analysis.

An attempt was made to extract some microfossils and spores from the Ireton Formation but the results were not encouraging. Distribution of macrofossils in the reef and their relation to porosity and permeability gave more conclusive results.

Finally a detailed log of the well has been prepared for the cored section (Figure 20-21).

Previous Work

The discovery of the celebrated Leduc oil field in 1947 gave a great impetus to the studies of Devonian reefs in Alberta. D.B. Layer, et al (1949) published one of the first detailed analysis of the Leduc oil field. Since then much work has been done by independent petroleum geologists and oil company personnel. One of the foremost workers has been Andrichuk (1954, 1958, 1961), who has published papers on Leduc, Stettler, Redwater and Duhamel oil fields. Fong (1960), Edie (1961) and Thomas and Rhodes (1961) published papers on the Swan Hills reef. Besides these, there have been many other notable general contributions on the Devonian oilfields of Alberta.

The only publication on the detailed facies aspect of the Duhamel reef is by Andrichuk (1961). He discusses the stratigraphic evidences for tectonic and current control in this area; in doing so he examined well sections from Cooking Lake and Duvernay Formations. Detailed accounts of lithologic and faunal features of Nisku and Leduc Formations of the Duhamel field have not been published to date.

STRUCTURAL CONTOURS
DUHAMEL FIELD
NISKU FM.(TOP)

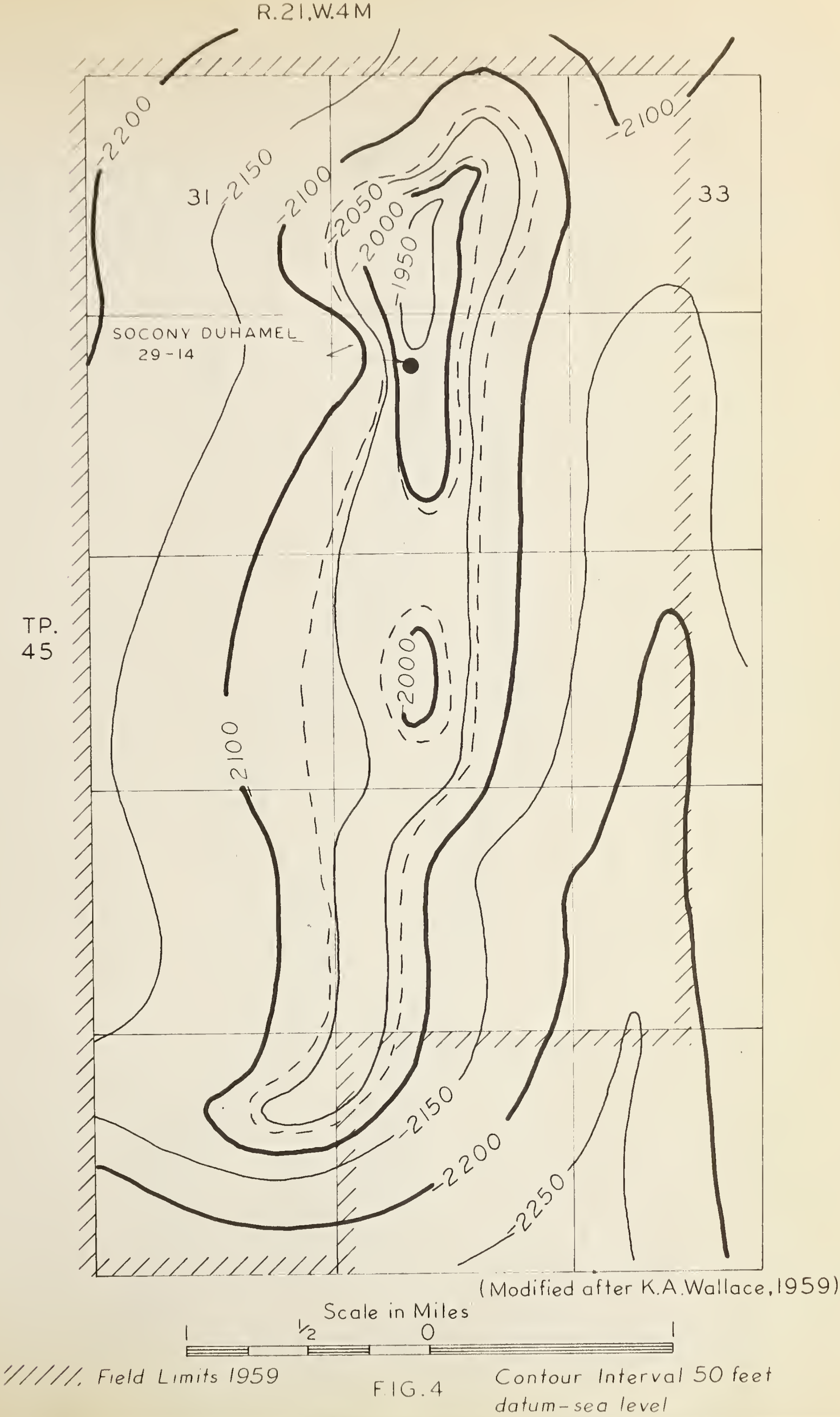
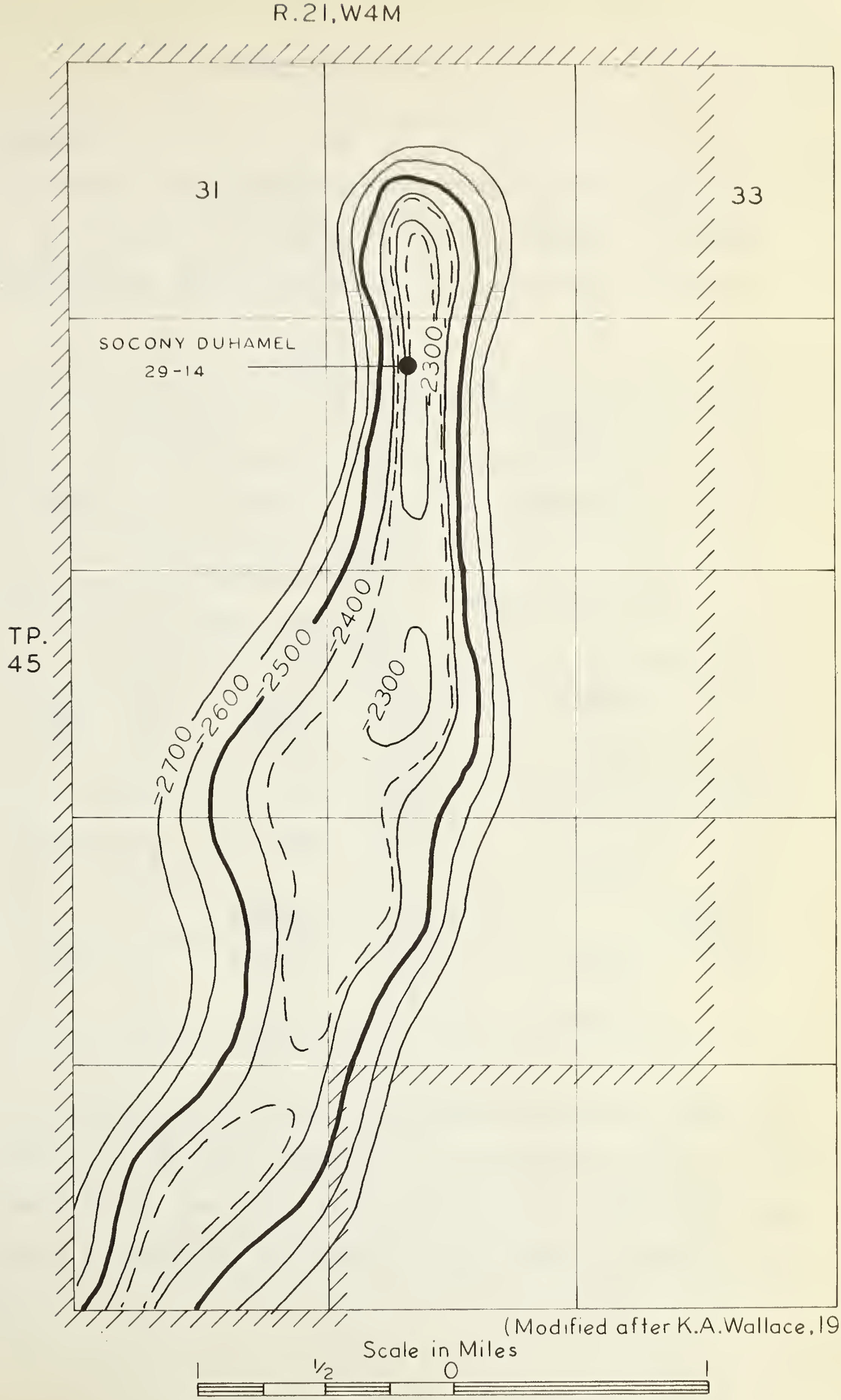


FIG. 4

STRUCTURAL CONTOURS
DUHAMEL FIELD
LEDUC FM. (TOP)



(Modified after K.A.Wallace,1959)

/////. Field Limits 1959   FIG. 5   Contour Interval 100 feet
datum - sea level

STRATIGRAPHY

General Statement

The Devonian stratigraphy of western Canada has been studied intensively; more so since the discovery of the Leduc oilfield in February 1947. A partial Upper Devonian correlation for Alberta is as follows:

TABLE 1

	MOUNTAINS		PLAINS	
	BANFF	JASPER	EDMONTON	
	Palliser Fm.	Costigan member Morro member	Wabamun Group (D_1)	
FAIRHOLME GROUP	Alexo	Alexo	Winterburn	Graminia Calmar
FAIRHOLME GROUP	Southesk	Mt. Hawk	Winterburn	Nisku (D_2) Ireton
FAIRHOLME GROUP		Fiddle	Woodbend	Leduc D_3
FAIRHOLME GROUP	Cairn	Perdrix Flume	Woodbend	Duvernay Cooking Lake

In the central Alberta plains the Cooking Lake Formation (approximately equivalent to the Flume Formations of the mountains) lies at the base of the Woodbend Group. The Leduc Formation overlies the Cooking Lake Formation and replaces the Duvernay and part of Ireton Formation in areas of reef development.

A temporary nomenclature for the Devonian beds in the Leduc field was first set up by D.B. Layer, et al (1949). Due to the complex nature of the reef development, rapid facies change, and lack of palaeontological evidence, no known formational names were used. The three main porous carbonate units were designated as D_1, D_2, and D_3.

The geological staff of the Imperial Oil Ltd. published a revised nomenclature for the Devonian in Edmonton area in 1950. Four new formation names were proposed which have since been raised to group status. These are in descending order: Wabamun, Winterburn, Woodbend, and Beaverhill Lake. The units are essentially rock-units and their age mostly Upper Devonian. Here the discussion will be confined to Winterburn and Woodbend Groups.

Winterburn Group

The type section of the Winterburn Group is 250 feet thick and lies between the depths of 4815 and 5065 feet in B.A. Pyrcz No. 1 well in Lsd. 12, Sec. 25, Twp. 50, Rge. 26, W. 4 Mer., Alberta. It includes three formations: Graminia, Calmar and Nisku (in descending order).

The Graminia Formation is buff, crystalline, silty dolomite. Its thickness at the type section is 150 feet. This has not been cored at Socony Duhamel 29-14.

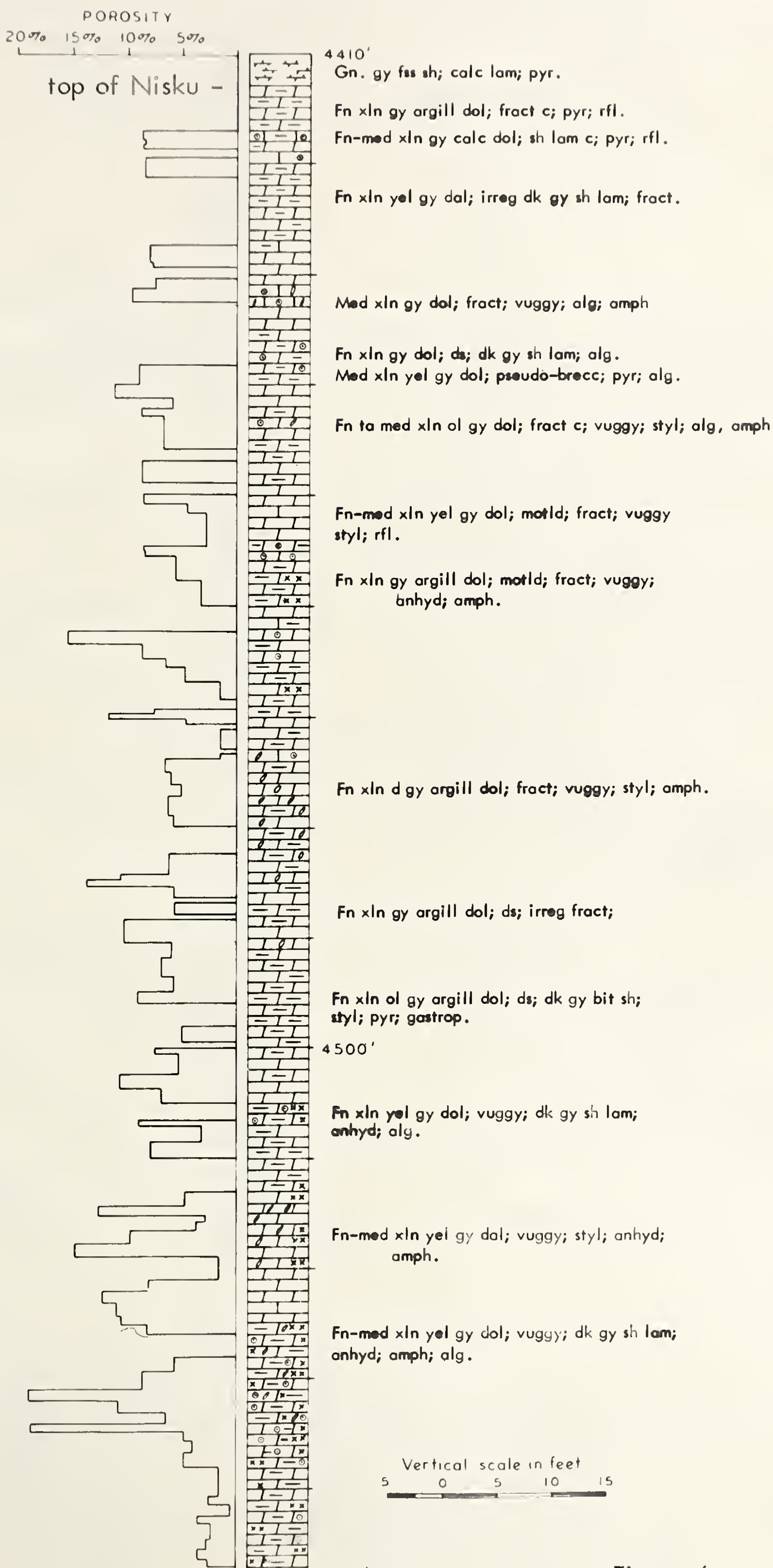
The Calmar Formation has a mottled, green and red appearance in the type section and is 44 feet thick. It was originally called "Red Bed zone". It can be readily distinguished on the radioactivity log due to its argillaceous content (Figure 3). The mottled character is not apparent in the Duhamel area. Here it is dark greenish-grey, calcareous shale. It is irregularly laminated and includes prominent pockets and stringers of pyrite. Only 11 feet were cored.

Section of Nisku Formation

WELL - SOCONY DUHAMEL NO: 29 - 14

LSD 14-29-45 - 21 - W. 4 M

DEPTH 4414' - 4548'



See Figure 20 for legend

Figure 6

Vertical and Radial Permeability Relationship in Nisku Formation, Duhamel Field, Alberta

Socony Duhamel 29-14

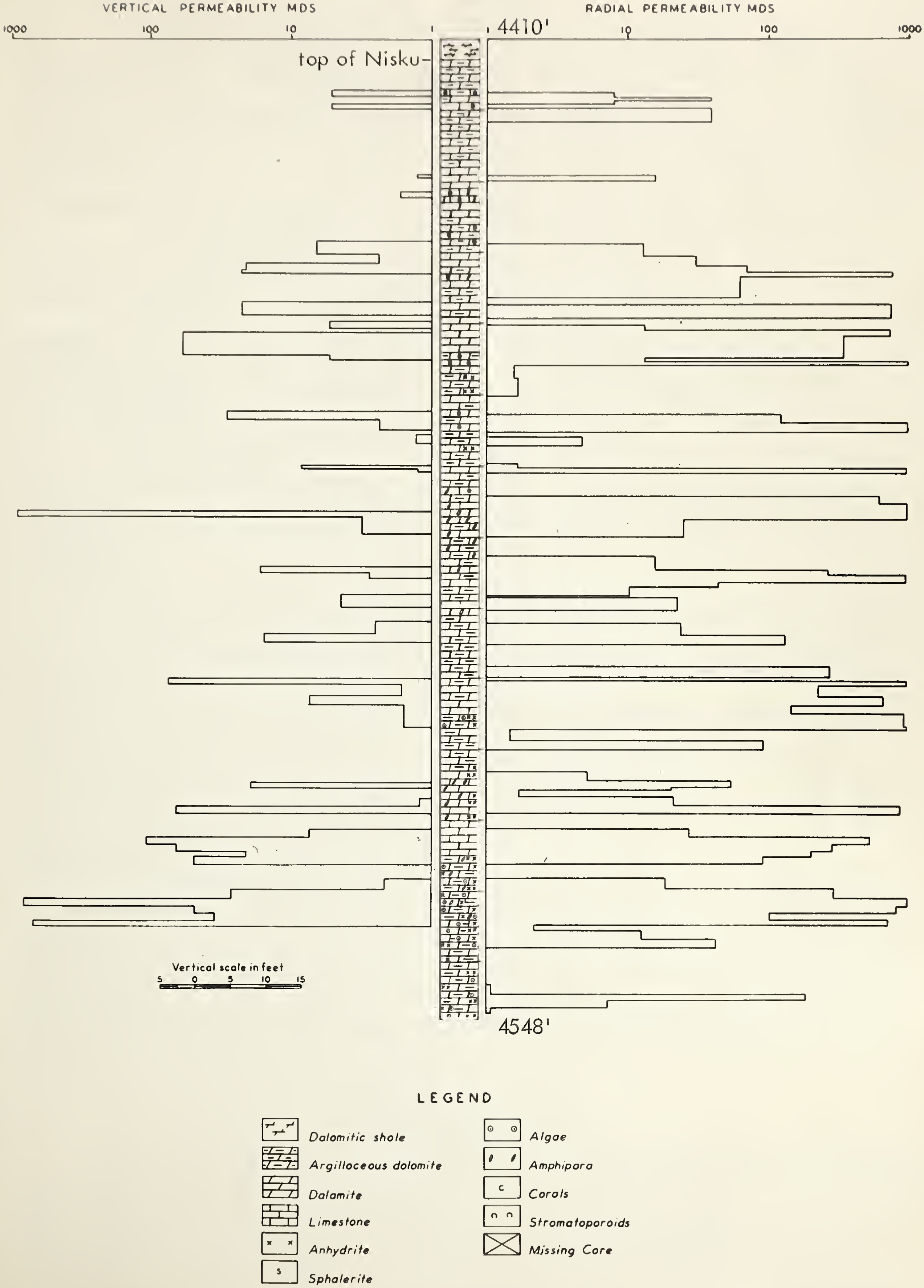


Figure 7

The name Nisku Formation was proposed by the Geological Staff of Imperial Oil Ltd. to designate a biostromal reef which overlies the Woodbend Group. It is the lowermost formation of the Winterburn Group. It was called the D_2 zone by Layer et al (1949). In the type area it is remarkably uniform in nature; consisting predominantly of dolomite with anhydrite occurring near the top. The thickness in the type locality is 156 feet. It contains commercial quantities of oil in the Leduc-Woodbend and Stettler areas, but at Redwater it is water bearing. In Socony Duhamel 29-14, the Nisku is an oil-producing horizon. It is 154 feet thick and occurs between depth 4,411-4,565 feet. As at the type area, it is predominantly dolomitic. The dolomite is fine to medium crystalline and usually porous. Shaly partings are common throughout. At places an increase in calcite reflects retention of organic structure.

One of the striking features of the Nisku Formation at Socony Duhamel 29-14 is that the basal 35 feet contain vugs filled with secondary anhydrite. This is in contrast to other Devonian reefs where anhydrite generally occurs near the top of the Nisku Formation and is a primary deposit. The basal portion of the Nisku Formation in Socony Duhamel 29-14 exhibits maximum porosity and a fair amount of algal development.

Weighted average porosity used by Mobil Oil engineers in Nisku Formation is 6.6 per cent, the maximum porosity recorded being 18.9 per cent. The average radial permeability is 218.7 md. and the average vertical permeability 29.3 md.; the maximum permeability recorded being 1785 md. (radial) (Figure 7).

Woodbend Group

The type section of Woodbend Group is 1135 feet thick and is at depths 5065 feet to 6200 feet in B.A. Pyrcz No. 1 well in Lsd. 12, Sec. 25, Twp. 50, Rge. 26, W. 4th Mer., Alberta. This group includes four formations which in

descending order are: Ireton, Leduc, Duvernay, and Cooking Lake.

The Ireton Formation is the uppermost of the Woodbend Group. In the off-reef sections, it overlies Duvernay Shale and underlies the Nisku Formation of the Winterburn Group. In areas where the Leduc bioherm is developed, the Ireton is thin.

At the type section, the Ireton Formation has been divided into two members: an upper dolomitic shale section and a lower calcareous shale section. Thickness ranges from 10 feet to 700 feet. At Socony Duhamel 29-14 well, the Ireton Formation is 136 feet thick, as interpreted from the radioactivity log, and occurs between depths 4565 to 4701 feet. The lowermost two feet, which has been cored, is a greenish grey, fine grained dolomitic shale and is characterized by finely disseminated pyrite crystals and nodules. It lies just above the Leduc Formation. The dolomitic nature of the shale indicates that only the upper dolomitic section of the Ireton Shale is found above the Leduc bioherm; the reef having developed at the expense of the shale. The relative ages of Leduc and Ireton Formations are somewhat controversial. Since Ireton Shale overlies the reef, it is in part younger; but the basal Ireton may be contemporaneous with the Leduc reef (Covenay and Brown, 1954).

The Leduc Formation in the type section is 603 feet thick. It is completely dolomitized and the reef is made up of bryozoans, stromatoporoids, corals and algae with some brachiopod and gastropod shells. Unlike the type section, the Leduc Formation of the Duhamel reef has completely escaped dolomitization. This feature is comparable to the Leduc Formation as found at the Redwater and Golden Spike reef complexes. At all these occurrences the Leduc forms a biohermal reef.

At Socony Duhamel 29-14, the Leduc Formation consists of non-bedded,

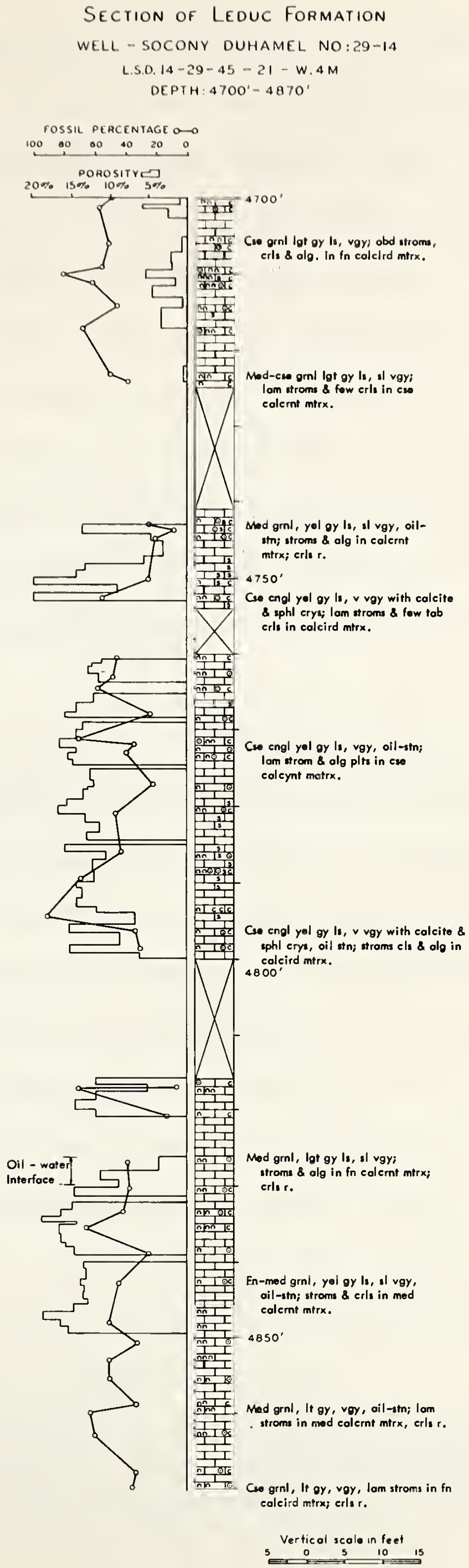

SECTION OF LEDUC FORMATION
WELL - SOCONY DUHAMEL NO:29-14
L.S.D. 14-29-45-21-W.4M
DEPTH: 4700'-4870'
FOSSIL PERCENTAGE
100 80 60 40 20 0
POROSITY
20% 15% 10% 5%
4700'
Cse grnl lgt gy ls, vgy; obd stroms, crls & alg. In fn calclrd mtrx.
Med-cse grnl lgt gy ls, sl vgy; lam stroms & few crls in cse calcrnt mtrx.
Med grnl, yel gy ls, sl vgy, oil-stn; stroms & alg in calcrnt mtrx; crls r.
4750'
Cse cngl yel gy ls, v vgy with calcite & sphl crys; lam stroms & few tab crls in calcird mtrx.
Cse cngl yel gy ls, vgy, oil-stn; lam strom & alg plts in cse calcynt matrx.
Cse cngl yel gy ls, v vgy with calcite & sphl crys, oil stn; stroms cls & alg in calcird mtrx.
4800'
Oil - water Interface
Med grnl, lgt gy ls, sl vgy; stroms & alg in fn calcrnt mtrx; crls r.
Fn-med grnl, yel gy ls, sl vgy, oil-stn; stroms & crls in med calcrnt mtrx.
4850'
Med grnl, lt gy, vgy, oil-stn; lam stroms in med calcrnt mtrx, crls r.
Cse grnl, lt gy, vgy, lam stroms in fn calcird mtrx; crls r.
Vertical scale in feet
5 0 5 10 15

Figure 8

light grey, bioclastic*, calcarenite and calcirudite and fossils. The matrix is generally composed of bioclastic debris composed of fragments of corals and stromatoporoids, algal pellets and other shell fragments. One of the characteristic features of the reef is the dominance of frame-building organic structures. Fracturing is evident throughout the formation. Clear, white crystals of calcite are very common in the vugs as infilling and lining along the margins. These secondary calcite crystals were probably formed when warm, aerated waters passed through the permeable reef growing structures. One of the most remarkable features of this reef is the occurrence of well-developed crystals of sphalerite in some of the vugs. They are, as a rule, sporadically distributed in the reef; but can be seen more often between the depths 4781 feet and 4794 feet.

The Leduc bioherm contains appreciable porosity. Both primary and secondary porosity is present. Intergranular porosity seems to be primary; solution porosity has developed vugs and cavities in place of original fossils. In addition, fine pores are present within the organic structures of such forms as amphiporids, stromatoporoids and corals. Weighted average porosity is 10.82 per cent, the maximum porosity recorded being 20 per cent. The average radial permeability is 400.6 md. and the average vertical permeability 273.2 md; the maximum permeability recorded being 2900 md. (vertical). On the whole the Leduc Formation shows greater porosity and permeability than the Nisku Formation. This is mainly due to the fact that it has completely escaped dolomitization. Figures 8 and 9 show porosity and permeability relationships to the stratigraphic column.

*The term 'bioclastic' was originally used by Grabau in referring to rocks composed of fragments formed through the breaking action of organisms. However, the writer has used this term to refer to fossiliferous-fragmental limestone broken by wave-action.

Vertical and Radial Permeability Relationship in Leduc Formation, Duhamel Field, Alberta

Socony Duhamel 29-14

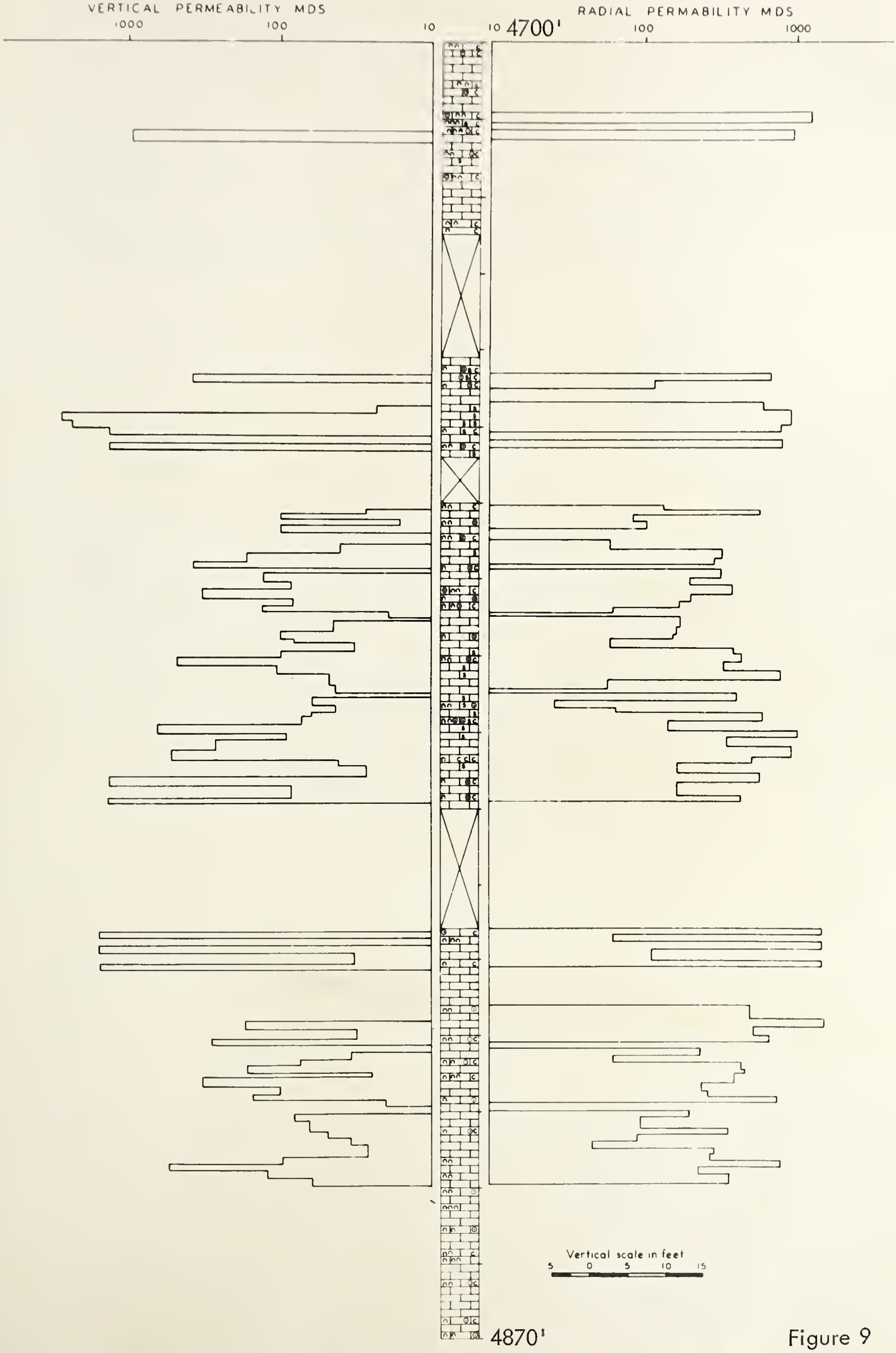


Figure 9

The Duvernay and Cooking Lake Formations of the Woodbend Group have not been cored at Socony Duhamel 29-14. Duvernay Formation is a shale facies found as an "off-reef" development. As in the type section, it is not present in the Duhamel area, where the reef facies is well developed. The Cooking Lake Formation in the type section is 240 feet thick and is buff, fragmental limestone. It has not been cored at Socony Duhamel 29-14, but apparently forms the reef platform in the region (see Figure 2).

PALAEONTOLOGY

The Duhamel reef shows a fair diversity of faunas. Although it was not possible to make an extensive study of fossils, an attempt is made to determine the distribution of the main fossil groups of the reef. Only small sections of Calmar and Ireton Formations were cored, so definite results could not be drawn regarding their faunal content. No fossils were found in the cored samples of Calmar and Ireton Formations.

The Nisku Formation, which is almost completely dolomitized, is marked by a paucity of fossils. However, irregular distribution of organic material throughout the samples is suggestive of some reefal character of the formation. In some places the organic development can be identified as algae. Presence of *Amphipora* is also a distinctive feature of the Nisku Formation. In some of the cores the *Amphipora* have been leached out, developing vuggy porosity. The lower portion of the Nisku (about 35 feet) shows a significant increase in the quantity of algal material and porosity, although this section is also anhydritic. One of the remarkable features of the Nisku Formation is the absence of corals and stromatoporoids. Extensive dolomitization might have destroyed these types of fossils.

In the Leduc Formation the main frame-building organisms were stromatoporoids and algae. Corals also form a very important assemblage of the Leduc bioherm. Due to the prolific development of corals, stromatoporoids and algae in this part of the Duhamel reef, it was decided to make a detailed study of the distribution of these three important components.

The outline of each fossil was traced out from the polished section and its area measured with a planimeter. In this way the percentages of corals, stromatoporoids and algae were calculated separately for each sample.

The total percentage of fossils in each sample was also calculated. The percentage distribution of corals, stromatoporoids and algae in the Leduc Formation is illustrated in Figures 10, 11 and 12. Figure 8 shows the percentage distribution of fossils against the stratigraphic column.

Increase in percentage of fossils is usually marked by an increase in the porosity (Figure 8). The exceptions to this rule are perhaps due to the irregular spacing of the samples. Leaching of fossils might also contribute to erroneous results in this type of interpretation. Although the fossil would dissolve, it would leave behind a cavity or vug which would increase the vuggy porosity even though the relative percentage of fossils in the core is reduced.

Although the Leduc Formation of the Duhamel reef has not been dolomitized, it has undergone a great degree of recrystallization. As a consequence of this latter, no specific identification could be made of the stromatoporoids or corals.

Of all the organisms, stromatoporoids appear to have had the most extensive development. They still show their laminations and "pillar-structure". Often they are associated with tabulate corals and algae. Presence of stromatoporoids are usually taken to mean a clear, shallow, warm and agitated water environment.

Corals identified in the Leduc Formation include the tabulate corals _Thamnopora_ s.l., _Thamnopora limitaris_ (Rominger), _Alveolites_, _Synaptophyllum_ sp. and certain other rugose corals. However, the _Thamnopora_-type tabulate corals are more abundant. Presence of these branching corals suggest well aerated, warm and shallow water conditions.

Organic structures which do not show 'pillar-structures' are considered as algae. There is a possibility that some of the 'algal-structures'

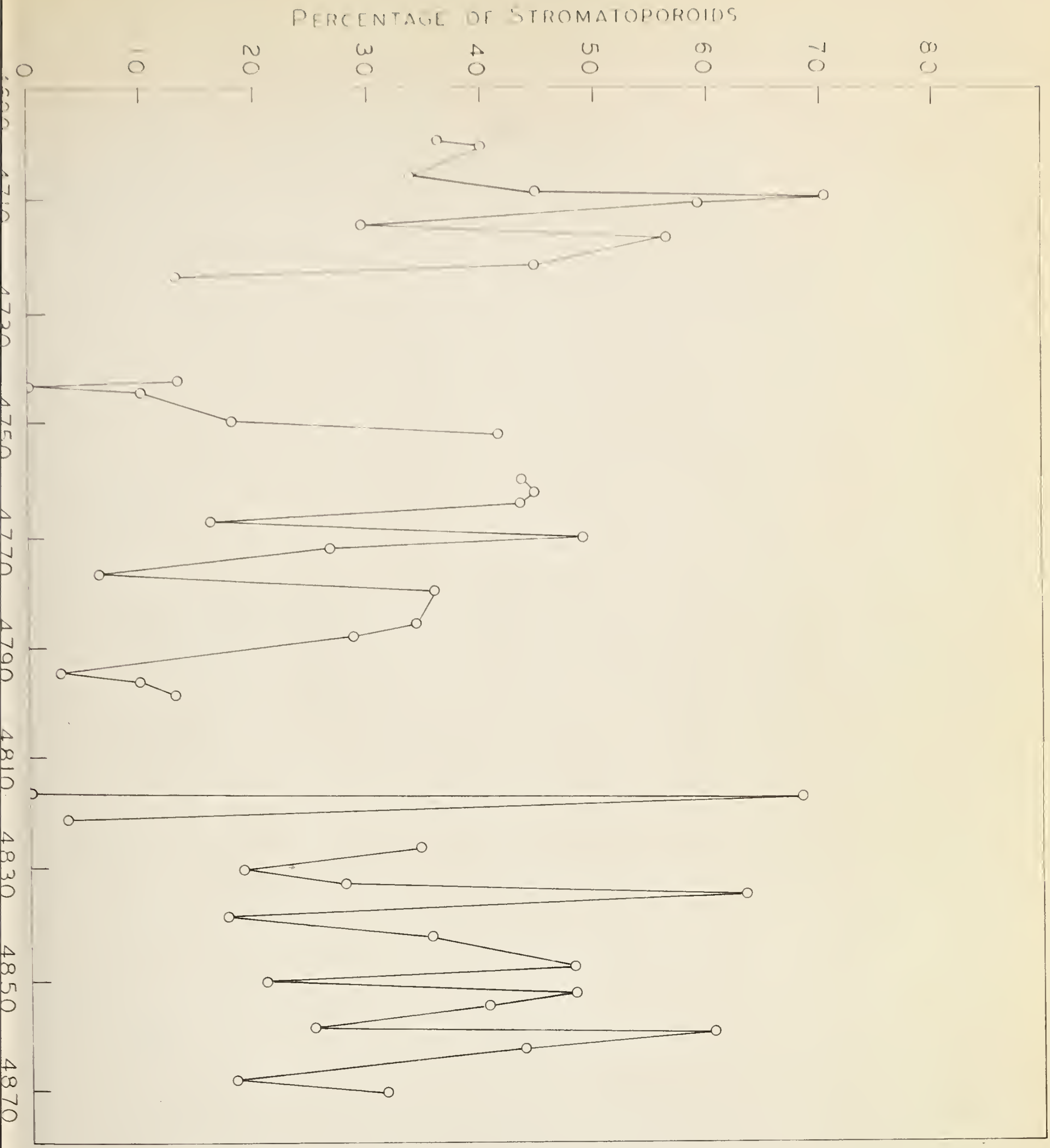


Fig. 10 Distribution of Stromatoporoids in Leduc formation, Duhamel Reef, Alberta.

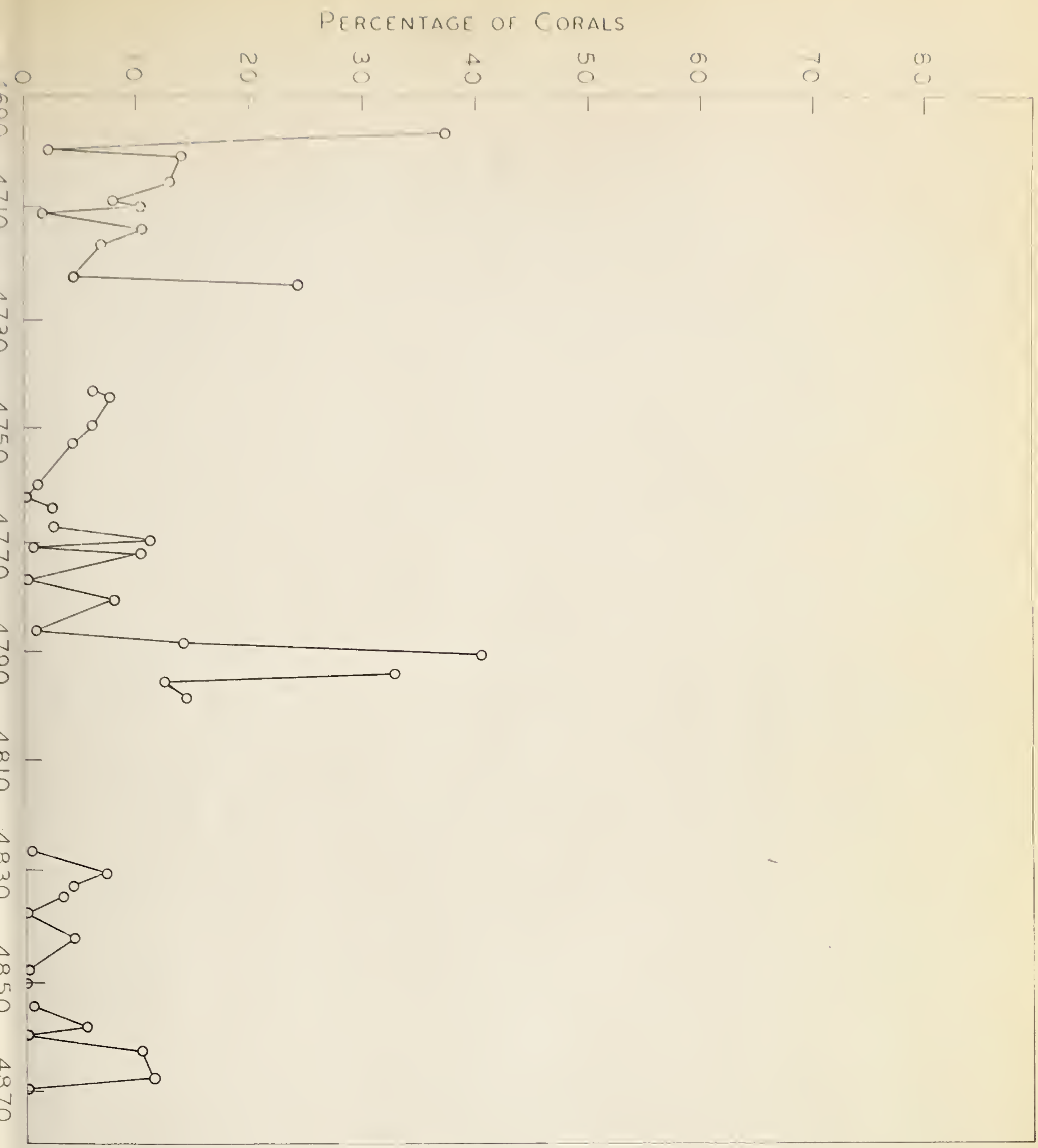


Fig. 11 Distribution of Corals in Leduc formation, Duhamel Reef, Alberta.

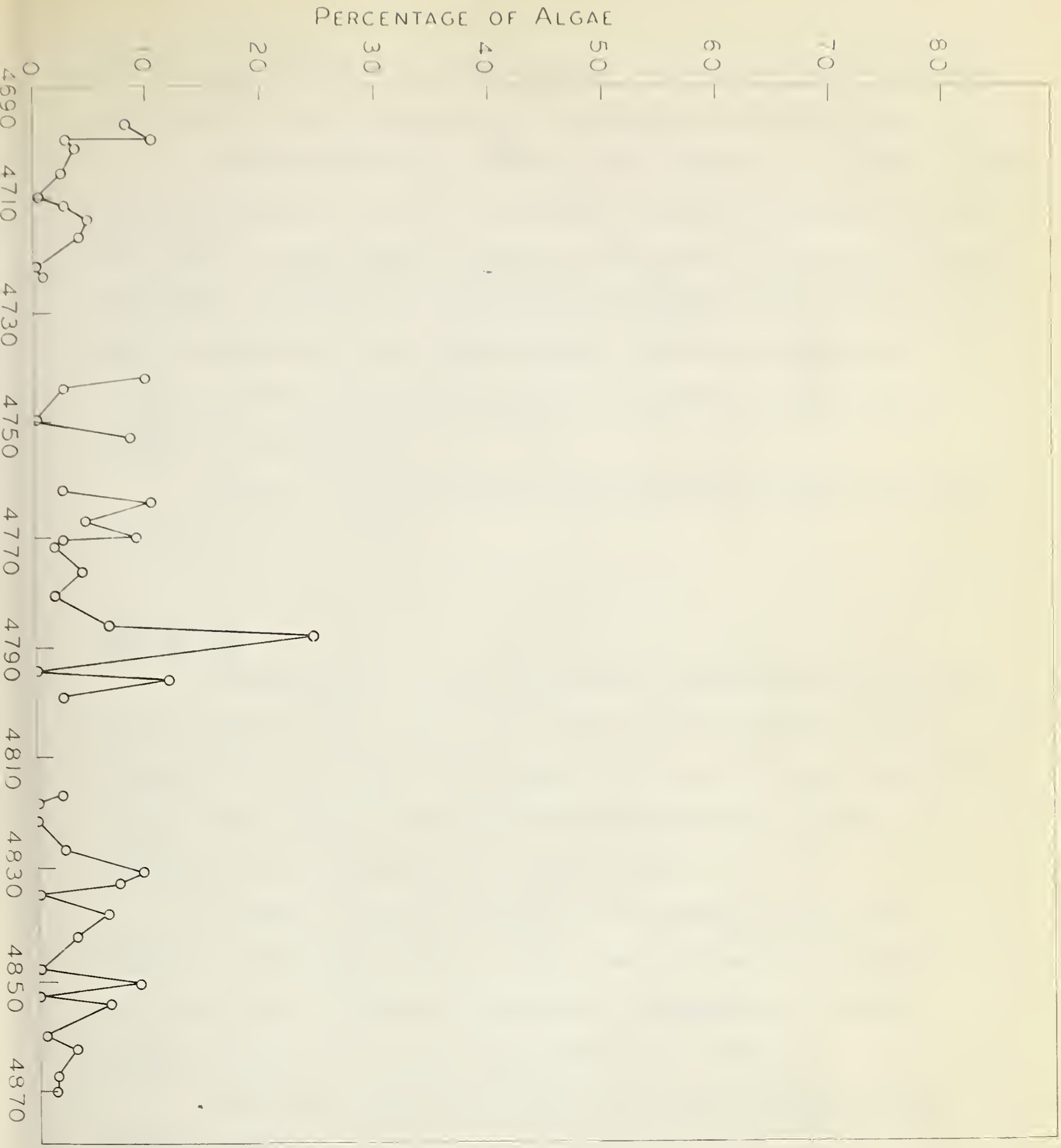


Fig. 12 Distribution of Algae in Leduc Formation, Duhamel Reef, Alberta.

may have been classified as stromatoporoids, but since most of the definite stromatoporoids show 'pillar-structure' the error should not be large.

No stromatoporoids s.s. or corals were recognized in the Nisku interval in Socony Duhamel 29-14 well. This suggests that the conditions of environment during the Nisku deposition were not conducive to the growth of stromatoporoids s.s. and corals. However algae and Amphipora were present in the Nisku Formation and indicate shallow water. They were apparently able to withstand considerably more variation in environmental conditions than corals and stromatoporoids.

Isolated casts of brachiopods and gastropods were found in the Nisku and in the Leduc intervals.

Microfossils

No microfossils have been reported from the Calmar and Nisku Formations. The microfaunal content of the Leduc Formation has been reported (Layer, 1949); but is scarce and meagre. The Ireton Shale has yielded more abundant microfossils. Loranger (1954) has reported the occurrence of conodonts and ostracods from the Ireton Formation.

An attempt was made to extract the microfossils of the Ireton Formation of the Duhamel well. As only a small portion of the formation was cored, only two samples were examined. Polygnathus sp., an Upper Devonian conodont, was the only fossil found in the samples.

A search for spores and pollens in the Ireton Formation yielded negative results.

Table II

Distribution of Fossils in Leduc Formation,

Duhamel Area, Alberta

Depth below surface in feet	Percentage stromatoporoids	Percentage corals	Percentage algae	Total percentage of fossils	Total percentage of matrix
4697.5	10.0	37.7	8.3	46.0	54.0
4700	37.0	2.0	10.0	49.0	51.0
4701.5	40.8	14.2	3.0	58.0	42.0
4706	34.8	13.0	3.3	51.1	48.9
4709	45.5	7.9	2.4	55.6	44.4
4710	71.5	10.5	0.0	81.8	18.2
4711.8	60.7	1.2	2.2	64.1	35.9
4714.2	30.0	10.6	4.8	45.4	44.6
4717	57.8	6.9	4.0	68.7	31.3
4723.3	45.5	4.3	0.0	49.8	40.2
4724.2	13.4	24.5	0.4	38.3	61.7
4743	13.9	0.8	10.0	24.7	75.3
4743.6	0.0	6.2	2.0	8.2	91.8
4744.5	10.7	7.7	2.3	20.7	79.3
4750	18.9	6.1	0.0	25.0	75
4752.5	42.5	4.2	8.3	55.0	45.0
4760.6	44.7	1.0	0.0	45.7	44.3
4763	45.5	0.0	2.5	48.0	42.0
4764.6	44.4	2.5	10.4	57.3	42.7
4768	16.6	2.7	4.2	23.5	76.5
4771	50.0	11.4	9.0	70.4	29.6
4771.8	30.7	0.5	2.3	33.5	66.5
4773.3	27.2	10.5	1.5	39.2	60.8

Table II [continued]

Depth below surface in feet	Percentage stromatoporoids	Percentage corals	Percentage algae	Total percentage of fossils	Total percentage of matrix
4777.4	6.4	0.0	4.5	11.5	88.5
4781	36.8	8.4	1.6	46.8	53.2
4786.7	35.0	1.0	6.5	42.5	37.5
4789.5	29.2	14.1	25.0	68.3	31.7
4794.7	3.0	87.0	0.0	90.0	10.0
4796.5	10.0	11.3	11.6	32.9	67.1
4798.8	13.6	14.2	2.1	29.9	70.1
4817	0.0	2.8	2.5	5.3	94.7
4817.1	69.5	0.0	0.0	69.5	30.5
4821	3.6	4.3	0.0	7.9	92.1
4826.9	35.0	0.5	2.5	38.0	62.0
4830.4	19.0	7.6	9.6	36.2	63.8
4833.4	28.3	4.8	7.2	40.3	59.7
4835.5	61.0	3.8	0.0	64.8	35.2
4839	17.8	0.0	6.2	23.6	76.4
4843	36.2	4.3	3.2	43.7	56.3
4848	49.2	0.0	0.0	49.2	69.3
4850.8	21.3	0.0	9.4	30.7	41.0
4853	49.0	0.0	0.0	49.0	51.4
4855.6	41.2	0.7	6.7	48.6	68.7
4859	25.4	5.9	0.0	31.3	38.0
4860	61.8	0.2	0.0	62.0	41.8
4863	44.2	10.6	3.4	58.2	41.8
4868	18.1	11.6	1.7	31.4	68.6
4870	32.3	0.0	1.5	33.8	66.2

PETROGRAPHY

Thin Section Study

A complete petrographic analysis of the cores of Socony Duhamel 29-14 well was made by a combined study of polished sections, acetate peels and thin sections. Thin sections were prepared from all the formations cored to study the textures, diagenesis, recrystallization and replacement effects.

The Calmar Formation is found to consists of finely laminated, calcareous shale. Pyrite was abundantly distributed as euhedral cubes, stringers and disseminated grains.

The Nisku Formation consists of unbedded, fine to medium grained dolomite, argillaceous in part, characteristically exhibiting stylolitic development. A thin section study revealed unmistakable evidence of replacement by dolomite. Fine to medium-grained, euhedral crystals of dolomite exhibit granoblastic texture and form a uniform mosaic pattern. Zoning in dolomite rhombs is a very characteristic and common feature throughout. There is a well developed rhomb in the center representing the dolomitized remnant of the original grain, and an irregular but clear development of dolomite around the periphery representing a later stage of dolomitization. The completeness of dolomitization is confirmed by X-ray analysis. Organic structures have been completely obliterated as a result of extensive dolomitization. Compared to the Leduc Formation porosity is poor and is mostly of the vuggy type.

Only one thin section was prepared of the upper Ireton, immediately above the Leduc Formation. The section showed a very fine, irregularly laminated, dolomitic shale. Pyrite was abundant as finely disseminated grains.

Leduc Formation. A study of thin sections from the Leduc Formation disclosed several interesting features of this biohermal, massive limestone. Textures range from medium-grained bioclastic calcarenite to almost

conglomeratic bioclastic calcirudites. With the exception of one thin section, the Leduc Formation showed no dolomitization. This latter was also confirmed by the X-ray analysis.

Recrystallization of the reef is evident, as most of the internal features of stromatoporoids, algae and corals are obliterated, rendering any specific study impossible. Calcite grains frequently show zoning, another evidence of recrystallization. In places secondary growth of clear calcite may be seen around a calcite grain. The interior is usually cloudy due to inclusions.

Intergranular and vuggy porosity is very common. Vugs are often lined with well developed crystals of calcite. In thin section calcite grains show development of incipient cementation or cryptocrystalline calcite overgrowth. As a rule the grains are loosely packed and devoid of cement, thus developing porosities up to 20 per cent. The large calcite grains stand out against a background of a matrix of bioclastic debris.

Sphalerite also occurs as secondary crystals in the vugs and cavities. Under the microscope the sphalerite is olive brown in colour with zones showing a purplish tinge.

A detailed description of thin sections is given in Appendix C (pp. 149).

Insoluble Residues and Heavy Minerals

Comparative studies of the insoluble residues and heavy minerals were made of the Nisku and the Leduc Formations. In addition, a similar study was also carried out of the Calmar and Ireton Formations. In no case were heavy minerals abundant or significant.

Procedure

The sample was crushed to small fragments (about 1/4" size) and weighed to 100 gms. It was then put in a litre beaker with 500 cc. commercial 1:1 HCl. The sample was heated on a radiator and allowed to stand for two to three days until the dolomite and calcite was dissolved.

The clear solution was decanted and the insoluble residue caught on a filter paper, dried and weighed. The percentage of insoluble residues thus obtained was calculated.

The 'heavies' and 'lights' were separated by centrifuging the residues, using bromoform (sp.gr. 2.85) as the separator.

Table III

Formation	Wt. of the sample in gms.	Wt. of insolubles in gms.	Percentage of insolubles
Calmar	100	54.6	54.6
Nisku	95	6.5	6.7
Ireton	90	61.0	67.7
Leduc	92	0.8	0.86

Socony Duhamel 29-14

Diagnostic minerals are rare in the insoluble residues. Pyrite is the most abundant heavy mineral throughout; it occurs as euhedral cubes and also as subangular to subrounded grains and is believed to be entirely autochthonous. Anhedral grains of silt size quartz are common in the Calmar and Ireton Formations. Infrequent and rare grains of hypersthene, tourmaline and kyanite were also identified. Well developed, angular grains of sphalerite are a remarkable feature of the Leduc Formation. Most of the grains are dark brown and some have a purplish tinge. Twin crystals of sphalerite are also common. The sphalerite is believed to be entirely secondary.

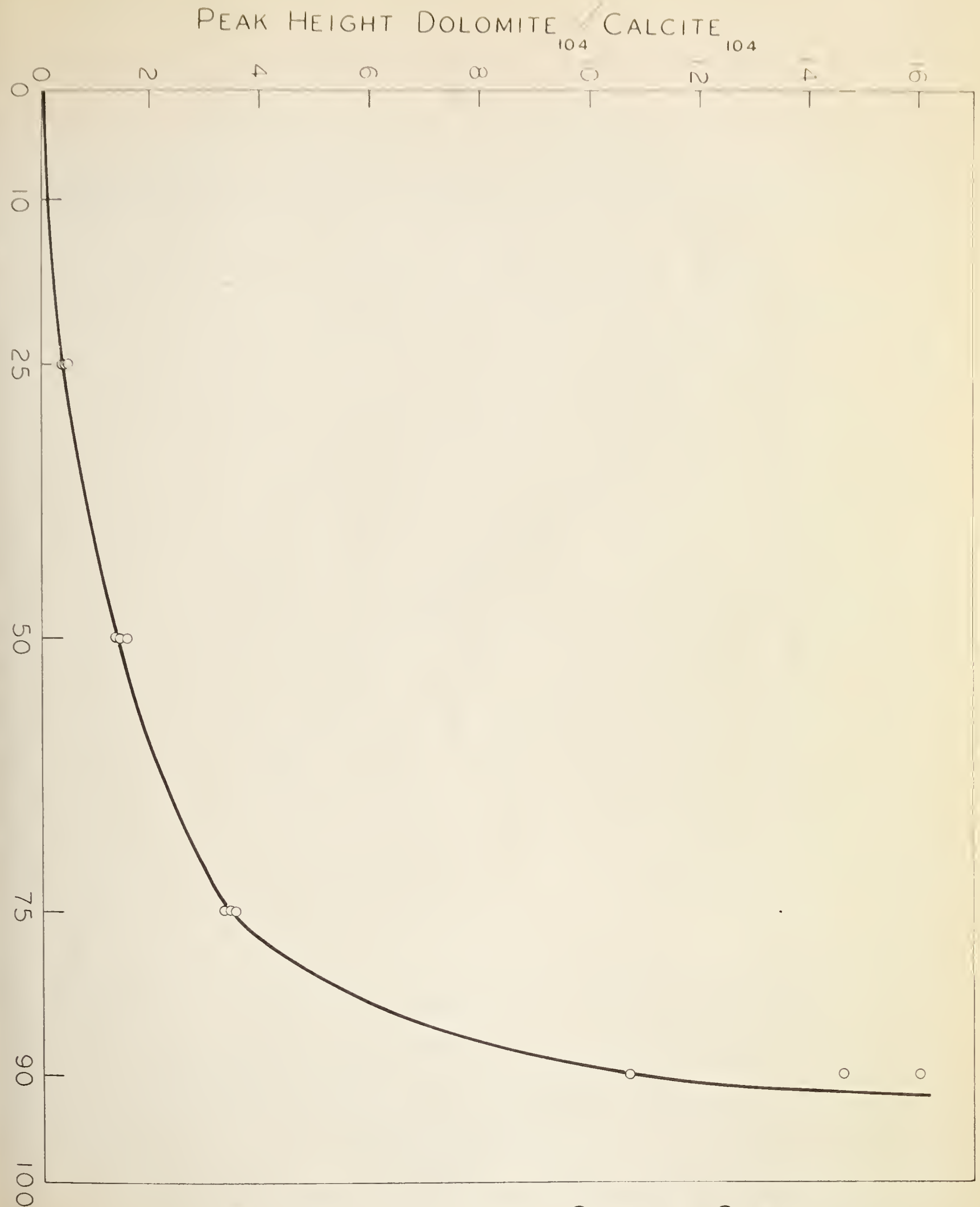
GEOCHEMISTRY

Dolomite-Calcite Ratios

In the present analysis of the Duhamel Reef, variation in dolomite-calcite ratios proved an important means of making a distinction between the Nisku and Leduc Formations. It seemed to reflect the state of preservation or the extent of obliteration of fossils in the undolomitized and dolomitized carbonate sections.

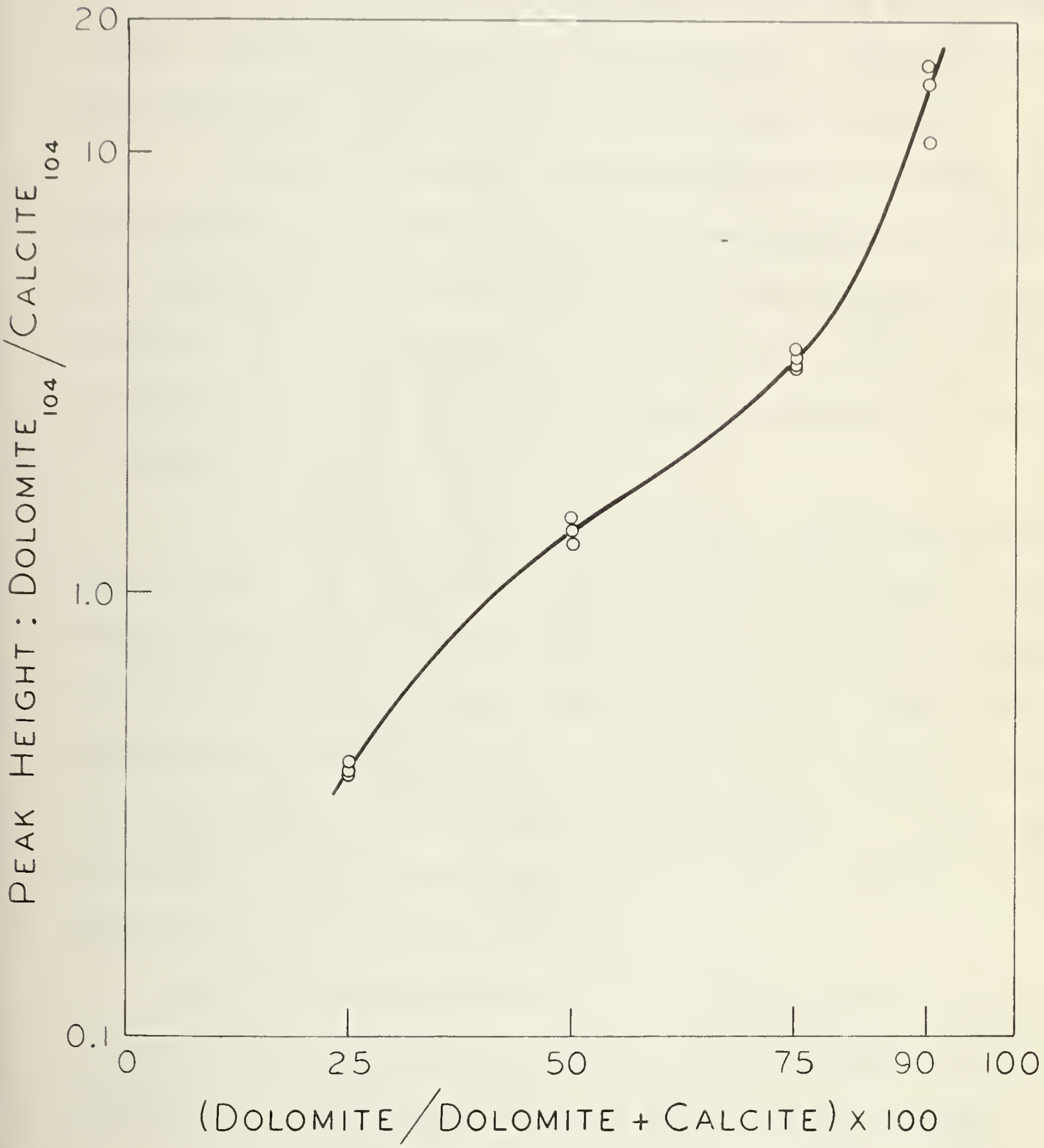
In the preliminary examination of the core samples, it was noticed that the samples from Nisku Formation showed no reaction when treated with 5 per cent HCl; whereas, the samples from the Leduc Formation effervesced readily on similar treatment. Apparently this is due to the variation in the dolomite-calcite ratios in the two formations. In view of the large number of samples to be analysed, the most suitable procedure is the X-ray diffraction technique. This method is quantitative and can also be performed fairly rapidly.

The standard procedure for preparing samples has been described in detail in Appendix D. Pure samples of calcite and dolomite were used for setting up a standard curve. The samples were ground, mixed in known proportions and X-rayed. An aluminum holder with a rectangular depression was used as the container for the powdered samples. The standard curve (Figure 13) was obtained by plotting the peak heights of calcite_{104} and dolomite_{104} against percentage dolomite of the total dolomite plus calcite content. The peak heights were obtained for each sample by setting the goniometer of the X-ray unit at an angle $2\theta = 28°$ and running it to the angle $2\theta = 32°$ (2θ angle for calcite_{104} is 29.4° and for dolomite_{104} 31.02°). Each peak was checked thrice in three different mounts and the average result taken. The standard curve so obtained, when plotted on a logarithmic scale (Figure 14) is found to match the calibration curve of Tennant and Berger (1957).



Standard Dolomite–Calcite Curve

Figure 13



STANDARD DOLOMITE CALCITE CURVE

(Logarithmic)

FIG. 14

The samples from Socony Duhamel 29-14 well were prepared and X-rayed in exactly the same manner as the standard samples. The peak heights for $calcite_{104}$ and $dolomite_{104}$ were determined and the dolomite:calcite ratios calculated. The percentage of dolomite was then read from the standard curve. The results are shown in Tables IV and V. Figures 15 and 16 show per cent dolomite plotted against the stratigraphic columns.

A study of the results obtained shows that the Nisku Formation has been completely dolomitized. Calcite occurs sporadically, usually where algae are concentrated; but in the lower portion even the algae have gone over to dolomite. The Leduc Formation, on the other hand, shows no dolomitization; it also carries algae, but in addition shows an abundance of corals and stromatoporoids.

In the case of Leduc bioherm, separate samples were prepared for the matrix, corals and stromatoporoids. This was done in order to determine whether there was any variation in the degree of dolomitization between the matrix and fossils and whether any particular type of fossils were more susceptible to dolomitization than others. Only the topmost sample of the Leduc Formation showed any noticeable dolomitization. In this case the matrix was found to be more dolomitized than the corals. Generally, neither the matrix nor the fossils were dolomitized.

The dolomite-calcite ratio of the Ireton Formation indicates that the carbonate in the shale is dolomite. This shows that only the upper portion of the Ireton Shale is present above the Leduc bioherm.

Strontium Analysis

Secondary strontium in sedimentary rocks is mainly derived from strontium found in aragonite. Aragonite is one of the chief carriers of

Nisku Formation

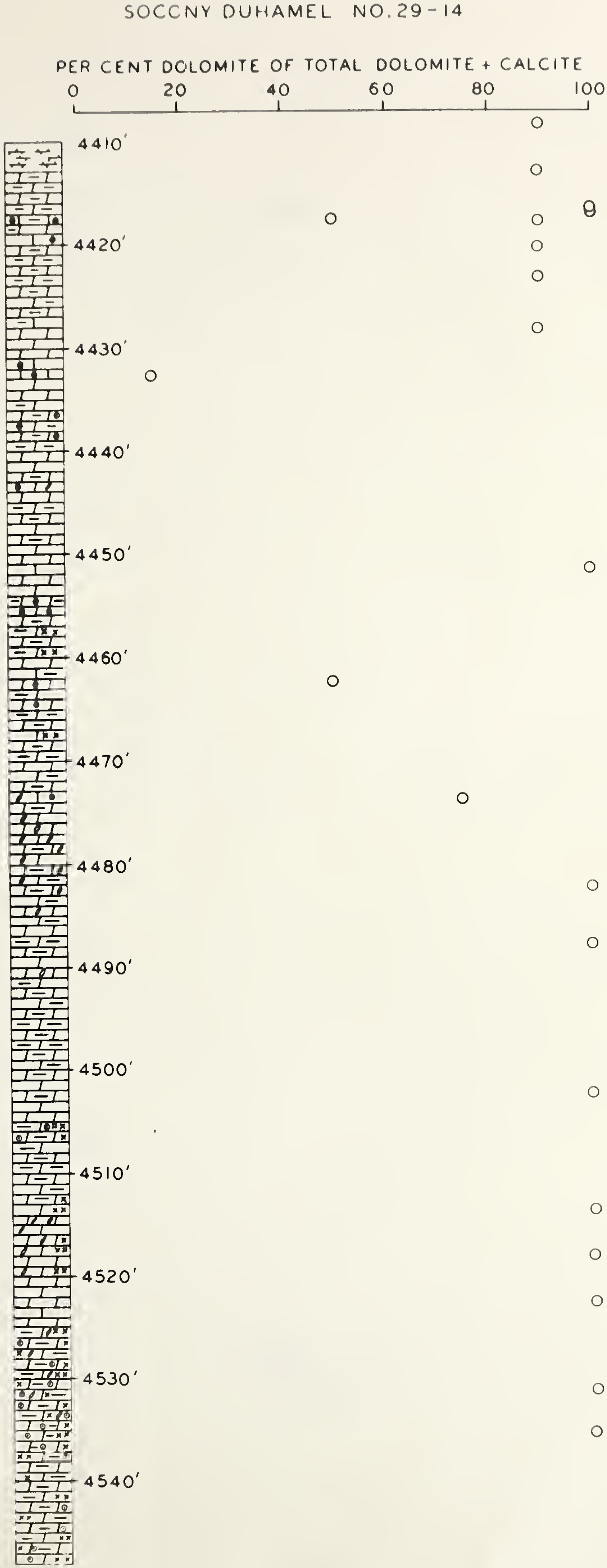
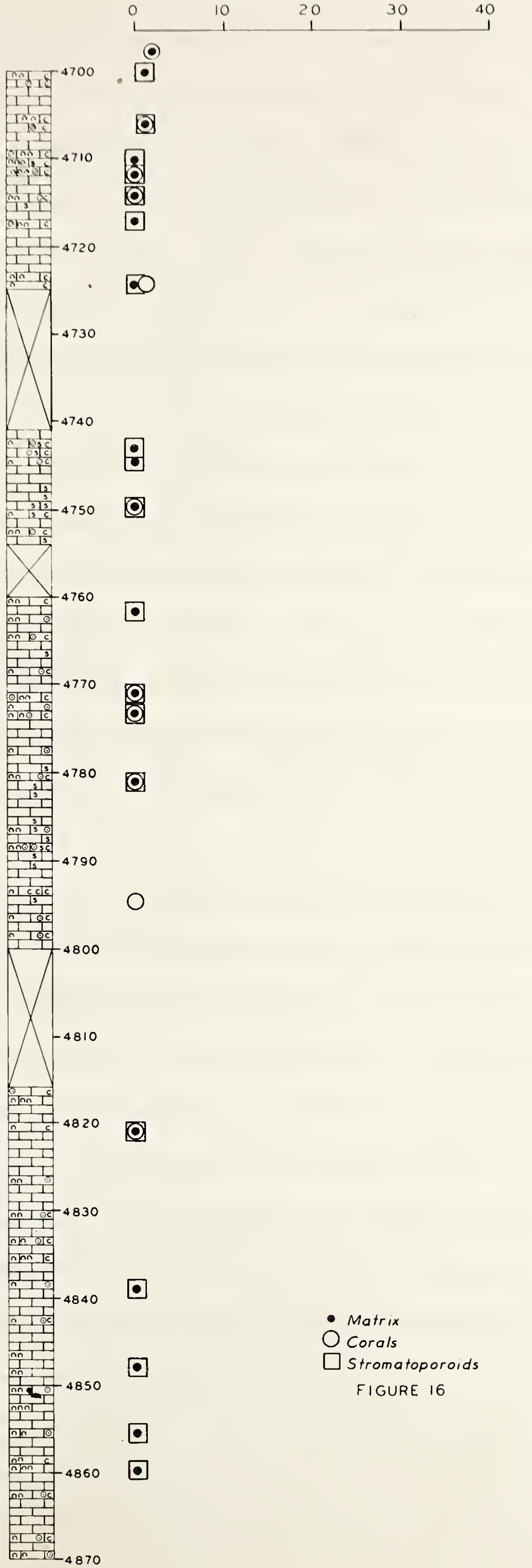


Figure 15

Leduc Formation

SOCONY DUHAMEL NO. 29-14

PER CENT DOLOMITE OF TOTAL DOLOMITE + CALCITE



• *Matrix*
○ *Corals*
□ *Stromatoporoids*

FIGURE 16

strontium among minerals formed during the exogenic cycle. Aragonite usually contains about 4 per cent strontium (Noll, 1934).

When aragonite is converted to calcite, strontium is set free and may migrate as sulphate. Fossils contain up to 4,250 g/ton strontium (Noll, 1934; Rankama and Sahama, 1955). Noll explained this manner of occurrence as ion for ion replacement of Ca^{2+} by Sr^{2+} in aragonite structure. Since aragonite is less stable than calcite, it is often converted into calcite or goes into solution, and in this way strontium is separated and reprecipitated as sulphate within the original fossil structure.

The geochemical data on concentration of strontium in sedimentary rocks and fossils has been very limited. Noll and Tsuchiya were the pioneer workers in this field. Odum made the first comprehensive study of biogeochemistry of strontium. Later, Kulp et al. (1952) supplemented Odum's work by studying the strontium content of limestones and fossils. Sternberg, et al. (1959) published an abstract on strontium content of calcites from a reef in Austria.

Some of the pertinent conclusions drawn from these studies are:

(a) Strontium content is low in recrystallized limestones.

(b) Shells with high aragonite content show higher strontium.

(c) Strontium content of fossils is higher than the matrix.

(d) Strontium content in the fore-reef is higher than in the back-reef, and highest in the basin area.

In light of these observations it was decided to study the distribution of strontium in the fossils and carbonate matrix of the Leduc bioherm. The X-ray fluorescence technique was used as it is very convenient and can be performed rapidly.

The procedure for preparing standards and unknown samples has been described in detail in Appendix E (pp. 169). Stromatoporoids and corals were separated from the samples by a vibro-tool. The instrument used for the analysis was a Norelco X-ray fluorescence unit. A standard sample was prepared by adding a weighed amount of reagent strontium nitrate (used as the source for Sr) to pure calcium carbonate. A standard stock sample containing 1000 p.p.m. strontium was thus prepared; by diluting this with calcium carbonate, samples with varying concentration of strontium were obtained.

These mixtures were made into pellets, using borax as a base. The working curve was then obtained by running the standard samples in the X-ray fluorescence unit, and plotting the peak heights obtained against the concentration of strontium in p.p.m. (Figure 17).

The samples from Socony Duhamel 29-14 well were prepared in exactly the same manner as the standard samples, and X-rayed for determination of strontium concentration; the peak heights determined, and the strontium concentration read off from the standard curve. The results are shown graphically in Figure 18 and in Table VI.

As indicated by the results, the strontium content in the fossils and matrix varies considerably throughout the Leduc Formation. There appears to be a decrease in strontium concentration with increase in depth. The inverse relationship is best displayed by the strontium concentration in the corals, and may be the effect of increase in recrystallization with depth. This is in agreement with the results obtained by Sternberg, et al. (1959) in their study of a fossil reef in the Austrian Alps.

The range of strontium concentration at Duhamel was appreciable, though not very high. It varied from 245 p.p.m. to 122 p.p.m. Sternberg, et al. (1959) reported strontium concentration in back reef areas between

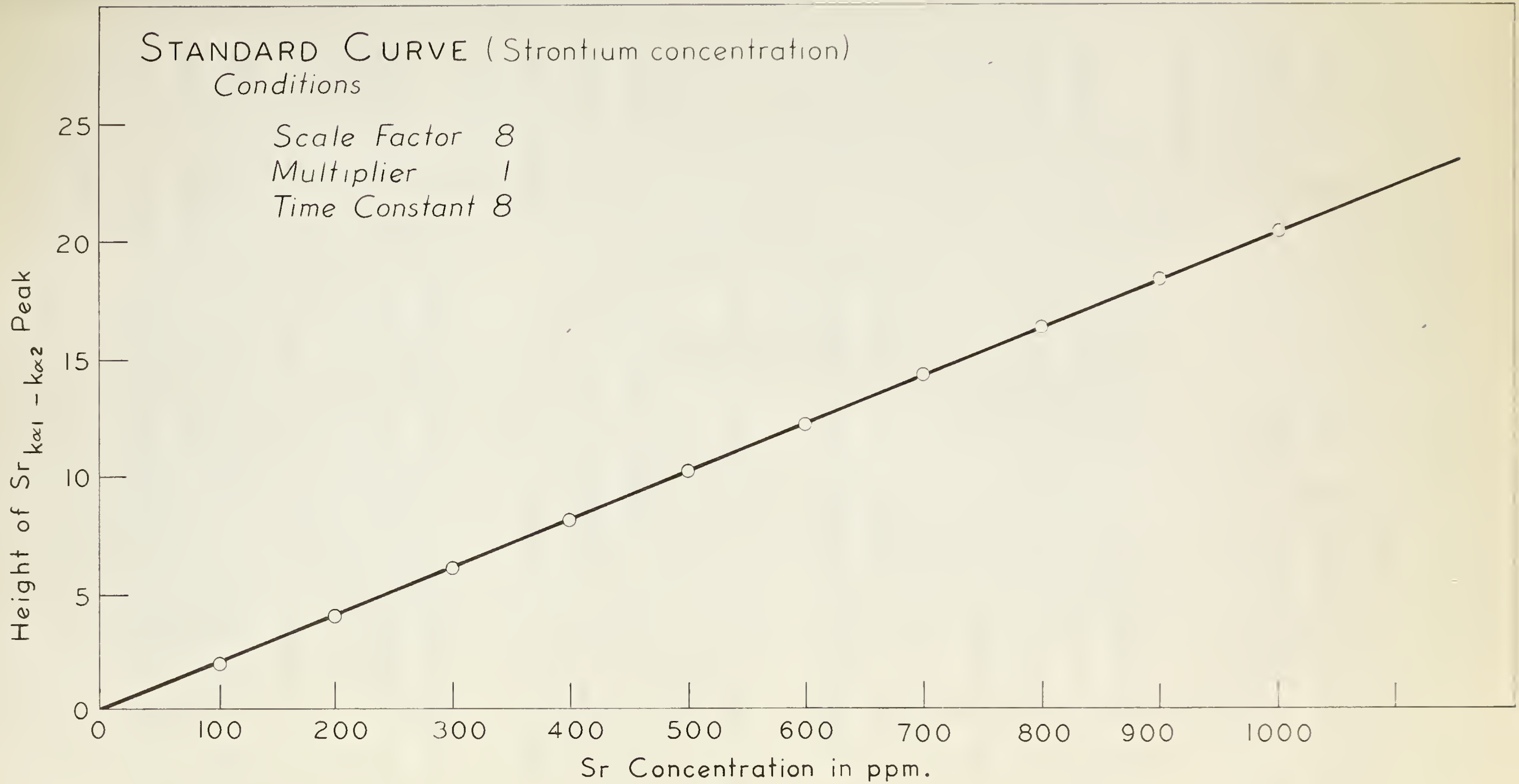

STANDARD CURVE (Strontium concentration)
Conditions
Scale Factor 8
Multiplier 1
Time Constant 8
Height of $Sr_{k\alpha 1} - k_{\alpha 2}$ Peak
0
5
10
15
20
25
100
200
300
400
500
600
700
800
900
1000
Sr Concentration in ppm.

FIG. 17

60 and 150 p.p.m.; in the fore-reef between 150 and 420 p.p.m. and in the basin area from 380 to 1570 p.p.m. As compared with these results, Socony Duhamel 29-14 well would be located in a fore-reef area. This is borne out by the position of the well as shown in Figure 5 and also by the lithologic and faunal study.

One of the striking features is the irregularity in strontium concentration in matrix with respect to fossils. Kulp, et al. (1952) reported that fossils have considerably higher concentration of strontium as compared to the matrix. However, in the case of the Leduc bioherm, there seems to be no such definite relationship. The relationship of strontium content between stromatoporoids and matrix is very irregular. The corals give a more regular relationship. Of the eight corals studied, six show greater concentration of strontium than the matrix.

These irregularities may be due to the fact that the matrix is mostly composed of bioclastic debris, which consists of fragments of corals, stromatoporoids, algae and other shell material. In this way the strontium concentration of the matrix is very much dependent on the composition of the bioclastic fragments. Its strontium concentration may be higher and results may be anomalous.

Since the stromatoporoids have a calcareous framework and are also recrystallized, their strontium concentration is perhaps secondary. Stromatoporoids show less strontium concentration than the corals. This suggests that the skeletons of the former were not rich in aragonite. Corals give the most useful results because their skeletons are aragonitic. Perhaps a greater number of samples would have given a better picture of the strontium distribution in the reef. However, the following conclusions can be drawn from results obtained:

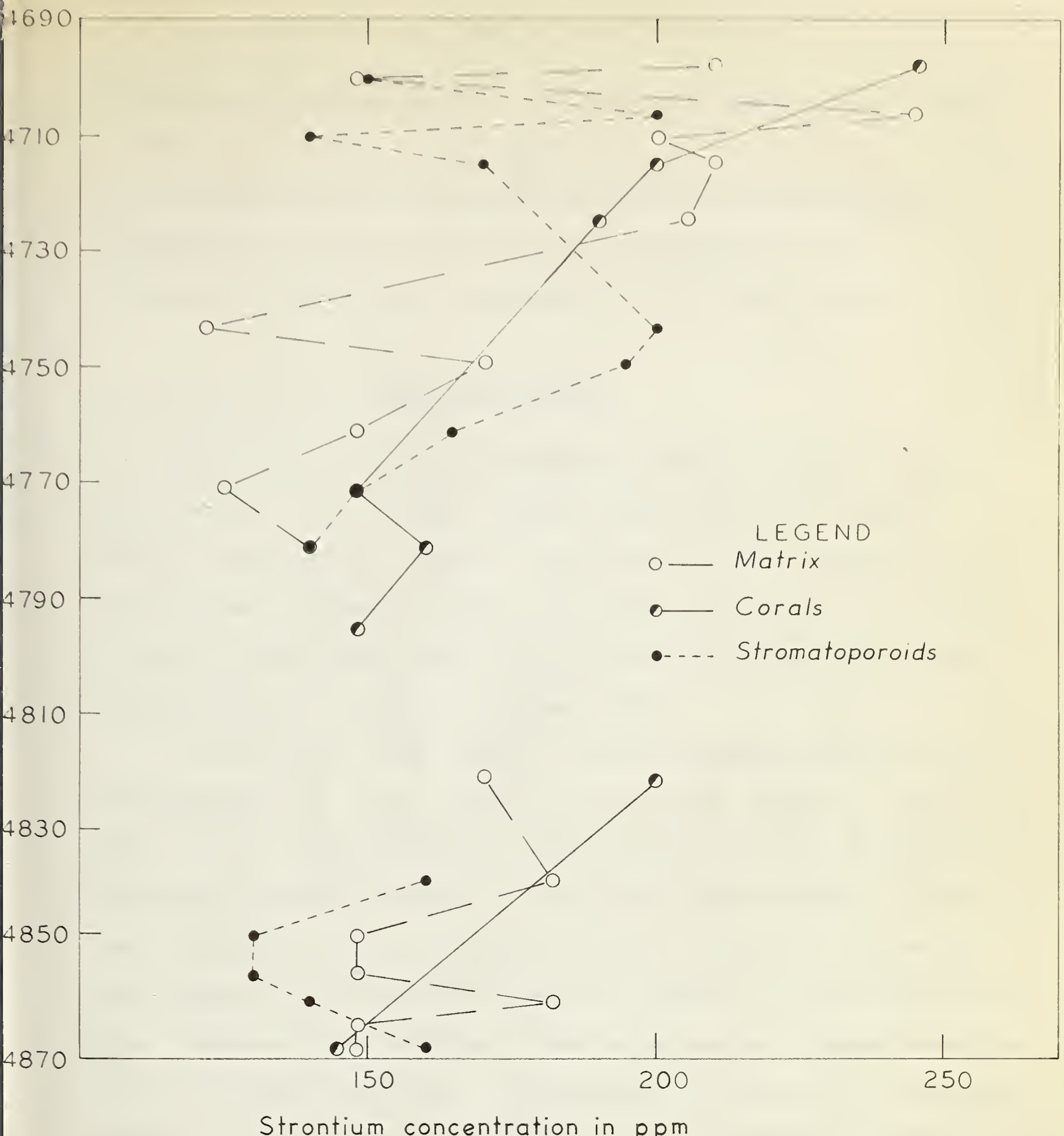


FIG.18 STRONTIUM DISTRIBUTION IN LEDUC FORMATION

DUHAMEL REEF, ALBERTA

(a) Amounts of strontium suggests a fore-reef environment at Socony Duhamel 29-14.

(b) Strontium concentration decreases with depth and recrystallization.

(c) Matrix gives anomalous results due to its bioclastic nature.

(d) Corals are better than stromatoporoids for this type of study.

Sphalerite Analysis

Significant occurrences of sphalerite have been reported from some of the Devonian reefs of central Alberta (Haites, 1960; R.E. Folinsbee, personal communication). Presence of sphalerite in Socony Duhamel 29-14 is one of the most remarkable features of this well. Sphalerite is also found in the Leduc reef of most wells of the New Norway and Malmo fields, which are on the same reef trend as the Duhamel field.

In the Duhamel field sphalerite has been reported from three wells, Socony Duhamel 29-11, Socony Duhamel 29-14 and Socony Flint No. 1 (Haites, 1960). In the Socony Duhamel 29-14, Haites cites occurrences of sphalerite in the Nisku Formation (at 4513 feet) and in the Ireton Formation (at 4585 feet), besides that found in the Leduc Formation. However, in the present study sphalerite was found only in the Leduc Formation of Socony Duhamel 29-14 well. Careful examination failed to show any occurrence of sphalerite in the Nisku or the Ireton Formations. The distribution of sphalerite in the Leduc Formation is shown in Figure 8. It occurs almost consistently in amounts ranging up to 2 per cent by weight from 4710 feet to 4790 feet and is generally found in vugs, along with secondary calcite crystals. When examined under the microscope it is often found to be associated with pyrite.

There appear to be two varieties of sphalerite in this reef. The non-magnetic sphalerite which is light tan in colour, and the magnetic

sphalerite which is dark brown to purplish black in colour. Under the binocular microscope some grains showed a tinge of purple. Sphalerite grains were also examined in thin sections. They appeared olive green in colour (some having a purplish tinge), with good cleavage, very high relief and were found to be isotropic.

Minor Elements in Sphalerite

A Norelco X-ray fluorescence unit was used to determine the elements present in sphalerite. Sphalerite sample was ground to -325 mesh size and placed in a mylar holder having a round hole as the sample container. The hole was filled just to the top and the upper surface smoothed off. It was then placed in the carrier and continually rotated during analysis to increase the homogeneity. The instrument was operated at 50 kv. and 40 ma. at two degrees per minute with scale factor 16, multiplier 1 and time constant 4 seconds. The goniometer of the X-ray unit was placed at $2\theta = 12°$ and allowed to run until $2\theta = 98°$. The peak heights obtained at various 2θ angles were noted and the corresponding elements determined with the help of Power's Conversion Tables.

The elements thus found were iron, cadmium and copper. Manganese was conspicuous by its absence. Warren and Thompson (1945) have analysed 122 sphalerites from Western Canada. They report cadmium, iron and copper as the "always present" minor elements. They found manganese in more than three-quarters of the samples and regard it as a "usually present" minor element. Rare elements like germanium, gallium and indium, etc. were not found in the sphalerite of the Duhamel reef. They are generally low or absent in the sphalerites from Western Canada.

Temperature of Formation

The iron content of sphalerite can be used as a geothermometer. Kullerud in 1953 showed that in the system FeS-ZnS, the amount of FeS in sphalerite is a function of the temperature of formation, if there is an excess of FeS present when the mineral is formed. According to Campbell (1959) the ZnS-FeS system will indicate the correct temperature only if the sphalerite is found in equilibrium with pyrrhotite. In the sphalerite from the Duhamel reef, no pyrrhotite is present and so the iron content in sphalerite will give only a minimum temperature.

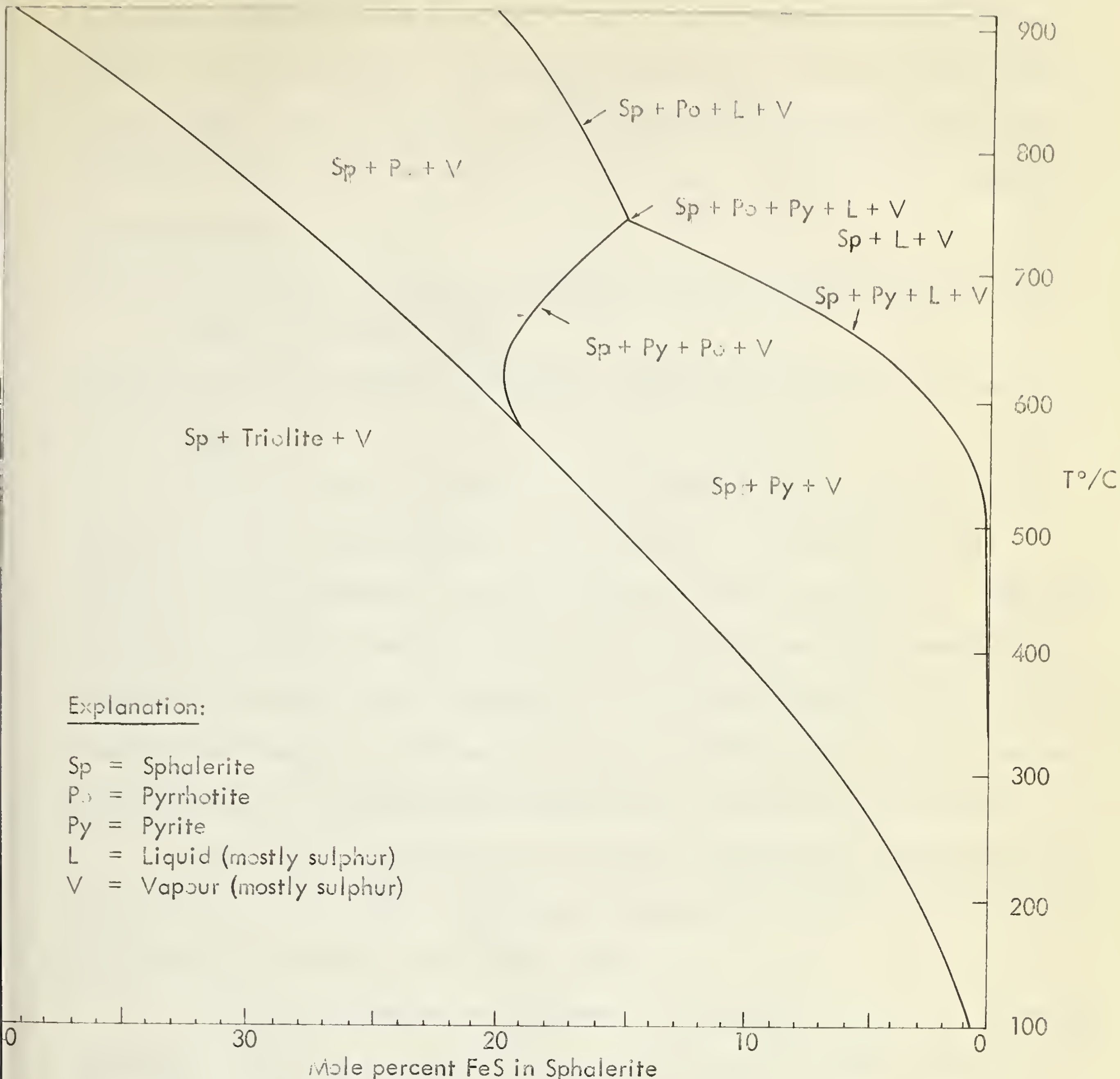
Two methods were used to determine the iron content in sphalerite:

(a) Measurement of lattice dimensions

An attempt was made to determine the iron content in sphalerite by using the measurement of lattice dimensions by X-ray diffraction method. The results were inconclusive. Smith (1955) showed that natural sphalerite contains both cubic and hexagonal packing and that the per cent hexagonal packing is higher in low temperature deposits. In light of this observation, Campbell (1959) states that in case of low temperature sphalerites, hexagonal packing influences the lattice dimension and thereby the peak position. Therefore a detailed study to determine the amount of hexagonal packing would be required before attempting any interpretation of the temperature of formation. Hence in case of low temperature sphalerites the use of lattice dimensions should be avoided.

(b) Chemical analysis

To carry out a chemical analysis, the sphalerite was hand-picked under the binocular microscope. An attempt was made to remove all contaminations from the samples, especially the pyrite grains. The sphalerite grains



Comparison of Sphalerite in equilibrium with various phases in Fe - Zn - S System.
[After Sims & Barton, 1961]

FIG. 19

were then crushed to -100 mesh and a heavy mineral separation was done to remove the calcite grains. Methylene iodide (sp. gr. 3.3) was used as the heavy liquid. After a fairly pure concentration of sphalerite grains was obtained, a magnetic separation was carried out. Two varieties of sphalerite were found:

(a) Light coloured, non-magnetic sphalerite; (non-magnetic at greater than 1.5 amp. and 1° tilt), and

(b) Dark coloured, magnetic sphalerite, (magnetic at less than 1.5 amp. and 1° tilt).

Chemical analysis of these two varieties of sphalerite was carried out to ascertain the percentage of iron present. Two analysis of non-magnetic and two analysis of magnetic sphalerite were carried out. The non-magnetic sphalerite gave an average of 0.33 mole per cent FeS, whereas the magnetic sphalerite gave an average of 1.19 mole per cent FeS. The FeS-ZnS equilibrium diagram as modified from Barton and Kullerud by Sims and Barton (1961) was used to determine the temperature of formation of sphalerite.

The minimum temperature of formation of non-magnetic sphalerite must have been less than 100°C. The minimum temperature of formation indicated for the magnetic sphalerite was at least 120°C.

A definite range of the temperature of formation cannot be determined when only pyrite is associated with sphalerite and the sulphur pressure is unknown. It can at least be said that the sphalerite in the Duhamel reef was formed at very low temperature. Further, as there are two varieties of sphalerite, there might possibly have been two stages of formation. The light coloured sphalerite with lower iron content might have formed at a different time than the dark coloured sphalerite. However, this variation in iron

content of sphalerite associated with pyrite can be caused by either or both, a change in temperature or a change in sulphur pressure (Sims and Barton, 1961).

Bottom Hole Temperature

Measurement of bottom hole temperatures is carried out in most of the wells after drilling is completed. It is important that temperature measurement be carried out after considerable time has elapsed since drilling and the rocks be given time to regain thermal equilibrium, otherwise this would give higher than equilibrium temperatures. Beach (1952) observed temperatures from 18 fields in Alberta and graphically represented the relation between bottom hole temperatures and depth. According to the gradients established by Beach the temperature at the top of Leduc Formation at Duhamel (4700 feet) would be about 55°C (130°F). By extrapolating the temperatures obtained from the Oil and Gas Conservation Board, the temperature at the same depth would be about 57°C (135°F). Since Socony Duhamel 29-14 was drilled in 1950 and the temperature measurement taken in 1958, the results obtained should reflect equilibrium conditions.

In these measurements no correction has been applied for the affect of denudation and erosion. According to Benfield (1949) denudation does not affect the temperature gradient unless the equilibrium heat flow is small and speed of denudation is rapid. Excessive burial is not apparent in the history of the Duhamel area.

By these means the minimum range of present formation temperatures can be inferred to be about 55°C.

Origin of Sphalerite

The occurrence of sphalerite and its origin in the Duhamel reef is still a controversial topic. According to several geologists it is associated with basement faulting. Haites (1960) infers that the occurrence of sphalerite in the Leduc reef at Malmo-New Norway and Duhamel fields indicates that mineralizing solutions moved up along faults that recurred in post-Nisku time. These faults were along the same locus that earlier had controlled the growing reef trend.

Andrichuk (1961) also suggests that basement faulting occurred during basal Duvernay sedimentation at the Duhamel field and this controlled the reef configuration.

The temperature measurements also indicate that though mineralization took place at low temperature, some of the sphalerite may have been deposited at a temperature about 65° higher than the present bottom hole temperatures at Duhamel. It appears reasonable to assume that mineralization was due to warm solutions moving along faults.

DEPOSITIONAL ENVIRONMENT

In the Duhamel area, the depositional environment can be ascertained by the biofacies and lithofacies study. Since the Socony Duhamel 29-14 well penetrates only the top portion of the Leduc reef, the environment during the early stages of reef growth is not considered.

According to Andrichuck (1961) "Leduc reef growth at Duhamel commenced essentially after the basal Duvernay calcilutite was deposited. Earliest or incipient patch reef growth was confined to the relatively positive eastern side of the line during Cooking Lake sedimentation. However, with differential subsidence along the aforementioned hinge line, the reef grew laterally westward, overlapping the thickest section of basal Duvernay calcilutite and the subsequent main reef buildup occurred on the interpreted downwarped, western side of the hinge line." Warren and Stelck (1954) also believe that reef building immediately succeeded the deposition of Duvernay Shale.

It is thus inferred that marine conditions favourable to organic reef development commenced after the deposition of Cooking Lake Formation. Initiation of this reef growing phase was marked by an increase in the rate of subsidence. As the bottom subsided the reef continued to grow upwards, keeping pace with the rate of subsidence and forming a bioherm. In this way the reef grew upwards continuously in the zone of wave action. Reef-building organisms such as tabulate corals and stromatoporoids flourished in the well-aereated, highly agitated water environment. Calcareous algae acted as the chief binding agent of the carbonate material. 'Rough water' or 'wave-resistant' stage (Lowenstam, 1957) is marked by an increase in stromatoporoids and corals. The abundance of these organisms in the well under study is in agreement with Lowenstam's results. According to Andrichuk and Wonfor (1954) the upward

growth was very rapid and in keeping with the high rate of subsidence and so prevented the development of penecontemporaneous dolomitization.

The uppermost part of the Leduc bioherm gives evidence of intensive destruction of the biohermal front by wave action. The rate of subsidence may have increased and caused the termination of the biohermal growth. Introduction and deposition of dolomitic shale may have been another contributory cause of stopping the reef-growth. In the off reef area the greenish grey shale changed in character from calcareous type to predominantly dolomitic type and there was a trend toward stability (Andrichuk and Wonfor, 1954). These epeirogenic changes marked the initiation of the biostromal phase of the Nisku sensu lato as the basin infilled.

Gradually the conditions again became suitable for existence of reef-building organisms; but the environment was not the same as at the time of Leduc Formation. The Nisku beds appear to have been deposited under conditions of greater stability and no opportunity for upward growth. Deposition must have taken place in relatively shallow and quiet water environment. Presence of pyrite indicates somewhat reducing conditions.

Secondary dolomitization has obliterated most of the primary features in the Nisku. At places, algae and amphiporids can be identified. There seems to be no indication of presence of stromatoporoids and corals; it therefore appears that conditions were not conducive to their growth. Secondary anhydrite fills vugs in the lower part of the Nisku Formation.

Reef building was completely stopped by additional shallowing and deposition of calcareous shale during the time of Calmar Formation.

SUMMARY AND CONCLUSIONS

The upper Devonian stratigraphic succession in the Duhamel area comprises two distinct types of organic carbonates--the Nisku "biostrome" and the Leduc bioherm. The well defined lithologic character of each formation found in the well, indicates that the area underwent marked environmental changes during upper Devonian sedimentation.

The Nisku "biostrome" is predominantly a fine-grained, greyish dolomite partly argillaceous in nature. Primary textures have been obliterated by dolomitization. Evidences of organic growth such as algae and Amphipora suggest that the original sediments were composed of an organic material which has subsequently been recrystallized. Absence of stromatoporoids and corals suggest that the environment locally must have been different from that found during Leduc sedimentation. Environment during the Nisku Formation also favoured dolomitization, that is, it must have been a warm, shallow, quiet, marine water environment.

Thin sections show granoblastic texture with zoned dolomite rhombs, suggesting two stages of dolomitization. Both intercrystalline and vuggy porosity are present but are relatively poor as compared to that within the Leduc bioherm.

One of the striking differences between the Nisku sedimentation in the Duhamel area as compared to the Nisku Formation of other Devonian fields in Alberta is the absence of primary anhydrite. No evaporite deposits are found at the close of the Nisku sedimentation. The only occurrence is secondary anhydrite which fills the vugs in the lower part of the biostrome.

The Leduc bioherm is an undolomitized reef, light grey in colour and totally devoid of stratification. It is composed of: (1) abundant stromato-

poroids, corals and algae, with many of the corals in growth positions, but near the top of the formation they are irregularly distributed and often truncated; (2) bioclastic calcarenites and (3) bioclastic calcirudites with matrix composed of fragments of corals, algal pellets and stromatoporoids. The assemblage of these frame-building organisms indicates a shallow, warm, clear, well aerated highly agitated water condition.

One of the most remarkable feature of this reef is that it has escaped dolomitization. This is a feature distinguishing this reef from the Nisku "biostrome" as well as from the Leduc reefs of many of the other Devonian oilfields of Alberta. Perhaps the rapid rate of growth which kept pace with rapid rate of sedimentation prevented any dolomitization. Further, the highly agitated and well aerated water conditions, as indicated by stromatoporoids and tabulate corals, were not favourable for dolomitization. Since the Duhamel reef lies in the extreme northern tip of the Malmo-New Norway-Duhamel reef trend and the currents were from the northeast (Andrichuck, 1961) the impact of water energy was most severe on the reef front. This probably caused rapid decomposition of calcium carbonate which along with highly oxidizing conditions proved less favourable for dolomitization. This has been suggested to be the case at the Redwater field which has also escaped dolomitization.

Very high intergranular and vuggy porosity is found throughout the Leduc reef. Porosity and permeability show a close relationship to each other. Further, porosity also increases with increase in percentage of organic material and increase in grain size.

A study of strontium content of the Leduc reef confirms it to be a fore-reef. Corals are most useful for evaluating strontium content. Matrix gives anomalous results because of the heterogenous bioclastic nature. The

strontium content is found to decrease with increasing depth and with the increase in the degree of recrystallization.

Presence of sphalerite is one of the most interesting features of the Leduc Formation at Duhamel. It is generally found in vugs, along with secondary calcite crystals and is also associated with pyrite. Two varieties of sphalerite were observed. (a) Non-magnetic, light coloured sphalerite and (b) magnetic, dark coloured sphalerite. The elements found in the sphalerite are iron, cadmium and copper. Manganese, which is often found in sphalerite, was absent. Chemical analysis of the sphalerite helped in determining the iron content and gave some indication of the temperature of formation. It was found to have formed at a low temperature though higher than present bottom hole temperatures.

On the whole the geological setting of the Leduc reef at Duhamel is similar to the Redwater field as outlined by Andrichuck (1958). The lithofacies and biofacies of the Nisku and Leduc Formations indicate different environments.

Because of lack of cores from Calmar and Ireton Formations, detailed study of these could not be performed. However, it was found that the Ireton formation lying above the Leduc reef was a dolomitic shale. This is in agreement with results obtained at other Devonian reefs in Alberta.

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APPENDIX A

Core Description

Company: Socony Vacuum Exploration Co.

Well: Socony Duhamel No. 29-14

Location: Lsd. 14-29-45-21-W4M

Depth below surface in feet	Description
	CALMAR
4404	SHALE: greenish grey, fissile; laminae irregular, slightly calcareous; specks of pyrite.
4404.3	SHALE: greenish grey, fissile; calcareous lamination more conspicuous (1 mm. - 3 mm.).
4407.5	SHALE: dark greenish grey, very fissile; laminae irregular and less frequent; stringers of pyrite.
4409.7	SHALE: greenish grey, fissile; laminae very thin, irregular, calcareous; pyrite prominent as well developed crystals and stringers.
4411.2	SHALE: as above.
	NISKU
4414.2	DOLOMITE: very fine grained, grey, shaly, dense; few fractures extending along shaly partings; development of reefal structure; stringers of pyrite present along fractures.
4415.1	DOLOMITE: very fine grained, greenish grey, shaly; laminations wavy and irregular; patches of reefal development; pyrite and minute fractures present.
4415.8	DOLOMITE: same as above, laminations even.
4416.2	DOLOMITE: very fine grained, grey, shaly, dense; dark grey bands of shale conspicuous throughout; horizontal and vertical fractures, often filled with pyrite; patches of reefal development.
4417.5	DOLOMITE: fine to medium grained, grey, slightly vuggy; reefal character very well developed; increase in calcite content; shaly bands conspicuous; fractures minute, horizontal and diagonal; contains irregular oil staining throughout.

Depth below surface in feet	Description
4419.8	DOLOMITE: fine grained, grey; vuggy in middle part along reefal development; somewhat shaly; secondary calcite filling along horizontal and vertical fractures; oil stained; patches of algal growth.
4422.9	DOLOMITE: very fine grained, yellowish grey, dense; interlaminated with dark grey bands of shale; horizontal and vertical fractures filled with calcite; dark grey bands of shale, particularly well developed at the two ends of the core.
4423.9	DOLOMITE: very fine grained, light grey, shaly, dense; minute fractures along shaly bands, vertical fractures filled with calcite; thick bands of shale (0.5 - 1 cm.), developed at the two ends of the core.
4425.2	DOLOMITE: fine to medium grained, mottled, yellowish grey, dense; irregular laminations of dark grey shale; very conspicuous vein of calcite (0.5 cms.) developed vertically across the core, cuts across and distorts the shaly bands; secondary fractures rare.
4427.8	DOLOMITE: fine grained, yellowish grey, very slightly calcitic, slightly vuggy; reefoid; dark grey shaly bands present; minute vertical fractures filled with calcite; stylolitic growth conspicuous; contains irregular oil stains.
4430.2	DOLOMITE: medium grained, yellowish grey, dense; mottled (pseudo-brecciated) in the upper part; no fracturing evident; stylolitic growth through the centre of the core, filled with hydrocarbons; slightly oil stained.
4431.6	DOLOMITE: fine grained, light grey, vuggy; secondary fractures filled with calcite; oil stained.
4432.5	DOLOMITE: fine to medium grained, light grey, vuggy; well developed calcite crystals in vugs; few minute vertical fractures; slightly oil stained; signs of algal and amphipora growth.
4436.9	DOLOMITE: fine grained, light grey, dense; interlaminated with dark grey bands of shale; no fracturing evident; oil stained at the bottom; slightly reefoid; bands of shale disturbed by algal growth on the left of the core.
4439	DOLOMITE: medium grained, yellowish grey, pseudo-brecciated, dense; half-inch band of dark-grey shale cuts across the lower half of the core; no fracturing evident; indications of organic development; few specks of pyrite; slightly oil stained.

Depth below surface in feet	Description
4440	DOLOMITE: fine to medium grained, light grey, dense; interlaminated with dark grey and greenish grey shale; laminations regular, somewhat silty; no fracturing evident.
4443.1	DOLOMITE: fine to medium grained, light olive grey, vuggy; horizontal and vertical fractures common; stylolitic development on the lower half of the sample; slightly oil stained; faint indications of growth of amphipora and algae.
4446.2	DOLOMITE: fine grained, light olive grey, dense, upper half of the core shaly--dark grey, laminated shale; vertical fractures in the dolomitic portion.
4446.7	DOLOMITE: fine to medium grained, light grey, vuggy, argillaceous; shaly portion irregularly laminated, dark grey; vugs filled with secondary calcite crystals; evidence of dolomitic replacement.
4450.7	DOLOMITE: fine to medium grained, yellowish grey, slightly vuggy, mottled, reefoid; fractures vertical; well developed stylolite through the center of the core; slightly oil stained.
4454.6	DOLOMITE: medium grained, olive grey, slightly vuggy, argillaceous; vugs filled with secondary crystals of calcite, slightly oil stained; faint algal development at the bottom of the core.
4455	DOLOMITE: fine grained, light olive grey, slightly vuggy; few fractures, extending in all directions; oil stained.
4455.5	DOLOMITE: fine grained, olive grey, vuggy, slightly argillaceous, vugs filled with well developed secondary crystals of calcite; slightly oil stained; algal growth quite marked.
4457.4	DOLOMITE: fine grained, medium light grey, slightly vuggy, mottled, argillaceous; few horizontal and vertical fractures; patch of anhydrite at the bottom of the core; oil stained; leached amphipora common.
4461.3	DOLOMITE: fine grained, light olive grey, dense; interlaminated with dark grey shale in lower half; half-inch band of shale in the middle of the core; fractures vertical; slightly oil stained.
4461.7	DOLOMITE: fine to medium grained, light olive grey, vuggy, reefoid; lower half of the core argillaceous; secondary calcite filling along cracks and vugs; oil stained.

Depth below surface in feet	Description
4462.5	DOLOMITE: fine grained, light olive grey, reefoid; minute stylolitic growth; heavily oil stained; faint algal growth.
4464.5	DOLOMITE: fine to medium crystalline, medium light grey, vuggy, some of the vugs one inch long; reefoid; well developed crystals of calcite in vugs; horizontal and vertical fractures present; patches of pyrobitumen seen at the bottom of the core; oil stained.
4465.5	DOLOMITE: fine grained, light olive grey, dense; irregularly laminated with dark grey shale; bottom of the core shows a pyrobitumen pocket.
4467.8	DOLOMITE: fine grained, light olive grey, slightly vuggy; pyrobitumen profusely developed; anhydrite present; oil stained.
4469.3	DOLOMITE: fine grained, medium grey, dense, argillaceous; no evidence of fracturing; half-inch band of calcite cuts vertically across one side of the core.
4473.8	DOLOMITE: fine to medium grained, light olive grey, dense, few minute fractures; oil stained; faint algal development.
4477.8	DOLOMITE: medium grained, light olive grey, vuggy, argillaceous, reefoid; vertical fractures few; well developed stylolite on the upper half of the core; oil stained; evidence of leached amphipora.
4482.7	DOLOMITE: fine grained, light grey, slightly vuggy, argillaceous, few vertical fractures; evidence of stylolitic development; faint indications of amphipora.
4488	DOLOMITE: fine grained, medium light grey, dense, argillaceous; minute irregular fractures, filled with dark grey bituminous material.
4490.9	DOLOMITE: fine to medium grained, olive grey, slightly vuggy; few vertical fractures; stylolite developed through the middle of the core; oil stained; evidence of leached amphipora.

Depth below surface in feet	Description
4496	DOLOMITE: fine grained, olive grey, dense, argillaceous; fractures filled with argillaceous material and in some places by pyrite; pyrite crystals well developed and irregularly distributed; dark grey, wavy bituminous shale partings and stylolites occur throughout the core. Gastropod.
4497.7	DOLOMITE: Same as above; band of dark grey, bituminous shale developed at the top of the core.
4500.6	DOLOMITE: fine crystalline, olive grey, dense; pronounced development of dark grey bituminous shale; stylolites filled with bituminous material; oil stained.
4502.5	DOLOMITE: fine crystalline, yellowish grey, slightly vuggy; vugs filled with secondary calcite crystals; dark grey stylolite, filled with bituminous material, developed in the lower half of the core; slightly oil stained.
4505.6 4507	DOLOMITE: fine crystalline, yellowish grey, vuggy; vugs filled with anhydrite and in places by secondary crystals of calcite; few dark grey shaly partings; oil stained; faint development and organic material.
4514	DOLOMITE: fine crystalline, dark grey, slightly vuggy; interbedded with dark grey bituminous shale; vugs filled with anhydrite; heavily oil stained.
4517.7 4518.5	DOLOMITE: fine to medium crystalline; yellowish grey, vuggy; slightly anhydritic; minute stylolitic development; oil stained; porosity due to leached out amphipora.
4526, 4531 & 4534	DOLOMITE: fine crystalline; yellowish grey, slightly vuggy, anhydritic; presence of dark grey shaly material; oil stained; evidence of growth of amphipora; algae.
4537.9	DOLOMITE: fine crystalline, yellowish grey, dense, having a pseudo-brecciated appearance; secondary anhydrite has completely sealed off the vugs, thus obliterating the porosity; definite indications of metasomatic replacement by anhydrite; few dark grey bituminous shale patches; faint development of algae.
4541.6	DOLOMITE: fine crystalline, yellowish grey, slightly vuggy; vugs filled with anhydrite; cracks, vertical and horizontal; scattered patches of dark grey, bituminous shale; slightly oil stained; faint development of algae.

Depth below surface in feet	Description
4547	DOLOMITE: fine crystalline, yellowish grey, slightly vuggy, argillaceous; vugs filled with secondary anhydrite; cracks vertical and horizontal; prominent bands of dark grey, bituminous shale, slightly stained, faint development of amphipora and algae.
	IRETON FORMATION
4697.3	SHALE: Greenish grey, fissile, very finely laminated; dolomitic.
	LEDUC FORMATION
4697.5	LIMESTONE: fine to medium granular, light grey, dolomitic, with minor, secondary anhydrite fillings; slightly vuggy; containing abundant scattered corals throughout in calcarenite matrix; corals mostly tabulate type (*Thamnopora*); "algal balls" conspicuous; truncated nature and irregular displacement of corals suggests deposition under high energy conditions.
4700	LIMESTONE: medium to coarse granular, light grey, slightly vuggy and oil stained; large, laminated stromatoporoids and their fragments in very coarse calcarinite to calcirudite matrix; composed of fragmental, fossil debris and algal pellets; corals rare.
4701.5	LIMESTONE: coarse granular, light grey, slightly vuggy and oil stained; abundant laminated stromatoporoid fragments in bioclastic matrix with algal pellets;few tabulate corals present.
4706	LIMESTONE: coarse granular, light grey, very slightly vuggy; abundant stromatoporoids and tabulate corals in very coarse calcarenite to fine calcirudite matrix composed of algal pellets; irregular arrangement of corals suggests highly agitated water conditions.
4709	LIMESTONE: medium to coarse granular, light grey, very slightly vuggy and oil stained; prolific development of stromatoporoids showing laminations and pillar structure; tabulate corals also present; coarse calcarenite to fine calcirudite matrix composed of fragments of stromatoporoids, corals and algal pellets.

Depth below surface in feet	Description
4710	LIMESTONE: coarse granular, light grey, vuggy, slightly oil stained; laminated stromatoporoids and their fragments in calcirudite matrix; corals few; algal pellets common.
4711.8	LIMESTONE: coarse granular, light grey, vuggy, oil stained; very large, laminated stromatoporoid along with smaller fragments, isolate corals and algal pellets in very coarse calcarenite to calcirudite matrix.
4714.2	LIMESTONE: coarse granular, light grey, slightly vuggy; stromatoporoids, tabulate corals and algal pellets in coarse calcarinite matrix; irregular displacement of corals indicative of agitated water conditions.
4717	LIMESTONE: coarse granular, light grey, very vuggy, some of the vugs about an inch long and lined with secondary calcite crystals; laminated stromatoporoid with 'pillar structure' developed right across the core; few scattered, tabulate corals; calcirudite matrix composed of fragments of stromatoporoids, corals and algal pellets; vuggy porosity from leached fossils.
4723.3	LIMESTONE: medium to coarse granular, light grey, very slightly vuggy; laminated stromatoporoid and few isolated corals in coarse calcarenite matrix composed of shell fragments and fossil debris.
4724.2	LIMESTONE: as above.
4743	LIMESTONE: medium granular, yellowish grey, slightly vuggy, heavily oil stained; stromatoporoids and algae in recrystallized calcarenite matrix; corals rare; high intergranular porosity.
4743.6	LIMESTONE: as above, but matrix tends to be coarser and more fragmental, toward bottom of the core shows distinct transition to light grey bioclastic limestone.
4744.5	LIMESTONE: medium granular, light grey, vuggy, one of the vugs about 1 1/2 inches long and 3/4 inch deep; large stromatoporoid and smaller fragments in bioclastic calcarenite matrix; corals few; imprint of a small brachiopod present.
4748.6	LIMESTONE: as above, but with more corals.

Depth below surface in feet	Description
4749.7	LIMESTONE: medium to coarse granular, light grey, vuggy; laminated stromatoporoids and tabulate corals in bioclastic matrix composed of algal pellets and fragmental fossil debris; high inter-granular porosity, cavities filled with secondary calcite crystals; few grains of sphalerite present.
4750	LIMESTONE: medium to coarse granular, yellowish grey, very vuggy, vugs often lined with secondary calcite and in some places by well developed sphalerite crystals; laminated stromatoporoids and tabulate corals in re-crystallized calcarenite matrix which in places become ruditic and contains algal pellets often 2 to 3 mm. in diameter; very high intergranular and vuggy porosity.
4751.5	LIMESTONE: medium granular, light grey, slightly vuggy, large sphalerite crystals, secondary calcite and pyrite in vugs, minute stylolitic development near the bottom of the core; numerous tabulate corals in calcarenite matrix; a few stromatoporoids.
4752.5	LIMESTONE: very coarse conglomeratic, yellowish grey, very vuggy, vugs filled with secondary calcite and few sphalerite crystals; large laminated stromatoporoids and few tabulate corals in coarse calcirudite matrix.
4760.6	LIMESTONE: coarse granular, yellowish grey, slightly vuggy, oil stained; laminated stromatoporoids and algal pellets in calcarenite matrix; corals absent; good inter-granular porosity.
4763	LIMESTONE: coarse conglomeratic, yellowish grey, very vuggy, vugs often filled with well developed secondary calcite crystals; oil stained; large, laminated stroma-toporoid and stromporoid fragments in calcirudite matrix, composed of algal pellets; corals rare, high vuggy and intergranular porosity.
4764.6	LIMESTONE: medium granular, yellowish grey, slightly vuggy, heavily oil stained; laminated stromatoporoids and algal pellets in calcarenite matrix; corals rare.
4768	LIMESTONE: medium to coarse granular, yellowish grey, vuggy; heavily oil stained; top of the core conglomer-atic, with laminated stromatoporoid, corals and algal pellets in calcirudite matrix; centre of the core even grained, with rare stromatoporoid fragments in calcar-enite matrix.

Depth below surface in feet	Description
4771	LIMESTONE: medium granular, yellowish grey, very vuggy, heavily oil stained; abundant stromatoporoid fragments and tabulate corals in calcarenite matrix; truncated nature and irregular displacement of fossils indicates highly agitated water conditions.
4771.8	LIMESTONE: coarse conglomeratic, yellowish grey, vuggy, vugs lined with well developed secondary calcite crystals; oil stained; large stromatoporoid in calcirudite matrix, mostly composed of algal pellets and fossil fragments; corals rare, mostly leached out; very high vuggy and intergranular porosity.
4773.3	LIMESTONE: medium to coarse granular, yellowish grey, vuggy, oil stained; laminated stromatoporoids and tabulate corals in recrystallized coarse calcarenite matrix consisting of algal pellets.
4775	LIMESTONE: medium to coarse granular, light grey, vuggy, oil stained; abundant tabulate corals and laminated stromatoporoids showing 'pillar-structure', in recrystallized coarse calcarenite matrix.
4777.4	LIMESTONE: medium to coarse granular, yellowish grey, slightly vuggy, oil stained; few stromatoporoid fragments and corals in recrystallized coarse calcarenite matrix, composed of algal pellets; good intergranular porosity.
4781	LIMESTONE: coarse granular, yellowish grey, vuggy; vugs lined with well developed calcite and sphalerite crystals; large stromatoporoid and numerous tabulate corals in biofragmental calcirudite matrix; good vuggy and interfragmental porosity.
4786.7	LIMESTONE: coarse granular, yellowish grey, very vuggy, some of the vugs more than an inch long, lined with well developed calcite and sphalerite crystals; bottom of core conglomeratic; large laminated stromatoporoid in calcirudite matrix, composed of algal pellets and fossil debris; corals few; high vuggy porosity.
4789.5	LIMESTONE: very coarse granular, light yellowish grey, vuggy, vugs often lined with secondary calcite and sphalerite crystals; fragments of stromatoporoids, corals and algae in calcirudite matrix; good vuggy porosity.

Depth below surface in feet	Description
4794.7	LIMESTONE: coarse granular, yellowish grey, vuggy, vugs lined with secondary calcite and sphalerite crystals; large well developed Alveolites; stromatoporoid and tabulate corals present in fine calcirudite matrix; good vuggy porosity.
4796.5	LIMESTONE: coarse, conglomeratic; yellowish grey, very vuggy, with calcite and sphalerite crystals in vugs, oil stained; some argillaceous material also present; stromatoporoids, tabulate corals and algae in bioclastic calcirudite matrix; good vuggy and intergranular porosity.
4798.8	LIMESTONE: as above but with slightly more argillaceous material, algal pellets common in calcirudite matrix.
4817	LIMESTONE: coarse conglomeratic, light grey, vuggy, oil stained; corals and algal pellets in recrystallized calcirudite matrix; stromatoporoids absent; small imprint of a brachiopod shell.
4821	LIMESTONE: coarse granular, yellowish grey, with patches of medium grey argillaceous material; vuggy, oil stained; rare corals and stromatoporoids in recrystallized calcirudite matrix, composed of algal pellets and bioclastic debris; good intergranular porosity.
4826.9	LIMESTONE: medium to fine granular, light grey, slightly vuggy; stromatoporoid and algal fragments in recrystallized, fine calcarenite matrix; corals rare; poor porosity.
4830.4	LIMESTONE: medium granular, light yellowish grey, vuggy, oil stained; fragments of stromatoporoid, corals and algae in medium to coarse calcarenite matrix; good vuggy porosity.
4833.4	LIMESTONE: medium granular, yellowish grey, slightly vuggy, oil stained; large stromatoporoid with fragments and corals in recrystallized calcarenite matrix; good intergranular porosity.
4835.5	LIMESTONE; as above but with greater percentage of stromatoporoids.
4839	LIMESTONE: medium granular, light grey, vuggy, slightly oil stained; stromatoporoids and algal pellets in bioclastic calcarenite matrix; corals absent; good vuggy porosity.

4843	LIMESTONE: fine to medium granular, yellowish grey, slightly vuggy, oil stained; fragments of laminated stromatoporoids and tabulate corals in medium calcarenite matrix, containing algal pellets; good intergranular porosity.
4848	LIMESTONE; coarse granular, light grey, vuggy, oil stained; fragments of laminated stromatoporoid in recrystallized, bioclastic calcirudite matrix; corals absent; very good vuggy and intergranular porosity.
4850.8	LIMESTONE: coarse granular, in parts conglomeratic, yellowish grey, and vuggy with lining of secondary calcite crystals in vugs, oil stained; few fragments of stromatoporoids in recrystallized, coarse calcarenite to calcirudite matrix; corals absent; good vuggy and interfragmental porosity.
4853	LIMESTONE: coarse granular, light grey, vuggy, with vugs filled with large crystals of secondary calcite; oil stained; numerous laminated stromatoporoid fragments in very coarse calcarenite to very fine calcirudite matrix; corals absent; good vuggy and interfragmental porosity.
4855.6	LIMESTONE: coarse conglomeratic, light grey, very vuggy with development of large crystals of secondary calcite in the vugs, slightly oil stained; numerous fragments of recrystallized stromatoporoid fragments in bioclastic, calcirudite matrix; corals absent; very good vuggy and intergranular porosity.
4859	LIMESTONE: medium to coarse granular, light grey, vuggy, with lining of secondary calcite crystals in vugs, slightly oil stained; few fragments of laminated stromatoporoids and tabulate corals in recrystallized coarse calcarenite, bioclastic matrix; good vuggy and intergranular porosity.
4860	LIMESTONE: medium granular, light grey, vuggy; slightly oil stained; large laminated stromatoporoids in recrystallized, medium calcarenite matrix; corals rare; fair intergranular porosity.
4863	LIMESTONE: medium to coarse granular, light grey, vuggy, slightly oil stained; large laminated stromatoporoids, tabulate and rugose corals in recrystallized, bioclastic calcarenite matrix; good vuggy and interfragmental porosity.

Depth below surface in feet	Description
4868	LIMESTONE: medium to coarse granular, light grey, slightly vuggy; large laminated stromatoporoid and tabulate corals in highly recrystallized very coarse calcarenite matrix; good intergranular porosity.
4870	LIMESTONE: coarse granular, light grey, vuggy; laminated stromatoporoids in recrystallized fine calcirudite matrix; corals absent; good intergranular porosity.

APPENDIX B

Acetate Peel Technique

Core specimens were diamond-sawed and polished. Final polishing was done by 600 grain carborundum paper. Great care was taken to keep the surface of the polished sections flat and even. Surface of the sample was then cleaned and dried.

Ten per cent HCl was used for etching the polished surface. Etching time varies for different specimens, depending upon their composition and texture. It was found that dolomites and dolomitic limestone required prolonged etching (as much as 2 to 3 minutes); whereas, undolomitized, bioclastic limestones etched readily in about 1/2 to 1 minute. Care should be taken not to over-etch the surface, especially if delicate coral structures are to be preserved.

0.1 mm thick acetate paper was found to be the best for making peels. Acetate paper was cut to slightly larger than sample size and placed on a flat surface--a uniform, thick rubber sheet. The etched surface was then wetted in acetone, making sure that entire surface was wet. The wetted surface was very quickly transferred onto the acetate paper and pressed uniformly and evenly for about a minute and then allowed to dry by itself and peeled off.

The peel was kept pressed between the pages of a book until further required.

The peel was then used as a negative in the enlarger to make the accompanying photographic plates. Orientation of the sections is indicated by title position. Top of the section is away from the title margin.

PLATE 1

NISKU

Organic development in the D_2 reef. The dolomitic and argillaceous portions are fine grained and compact. The organic (algal) development in the centre of the sample has given rise to vuggy and intergranular porosity (black areas). Fractures are filled with secondary calcite. Depth 4,417.5 feet. X4.

Plate 1

PLATE 2

NISKU

Algal development in fine grained argillaceous dolomite. Growth of algae is very well exhibited on the lower-right of the plate. Organic development has produced vuggy porosity. Horizontal and vertical fractures are partly filled with secondary calcite crystals. Depth 4419.8 feet. X4

Plate 2

PLATE 3

NISKU

(a) Interbedded dolomite and shale. Shale shows irregular laminations. Dolomitization and replacement is well exhibited, giving the sample a mottled appearance. Thick, secondary vein of calcite is seen running across the plate. Some of the calcite grains in the vein show rhombic cleavage. Secondary fractures are rare. Porosity absent due to compact nature of the fine grained argillaceous dolomite. Depth 4,425.5 feet. X4

(b) Continuation of 3(a). The curving of the shale bands is quite marked as a result of the secondary vein of calcite. Mottled nature of the dolomite is well exhibited. Depth 4,425.5 feet. X4

Plate 3(a)

Plate 3(b)

PLATE 4

NISKU

Stylolitic development in fine grained dolomite of the D_2 reef. Stylolite is filled with hydrocarbons. Secondary fractures are small and not very well developed. Bedding and porosity absent. Depth 4,430.2 feet. X4

Top

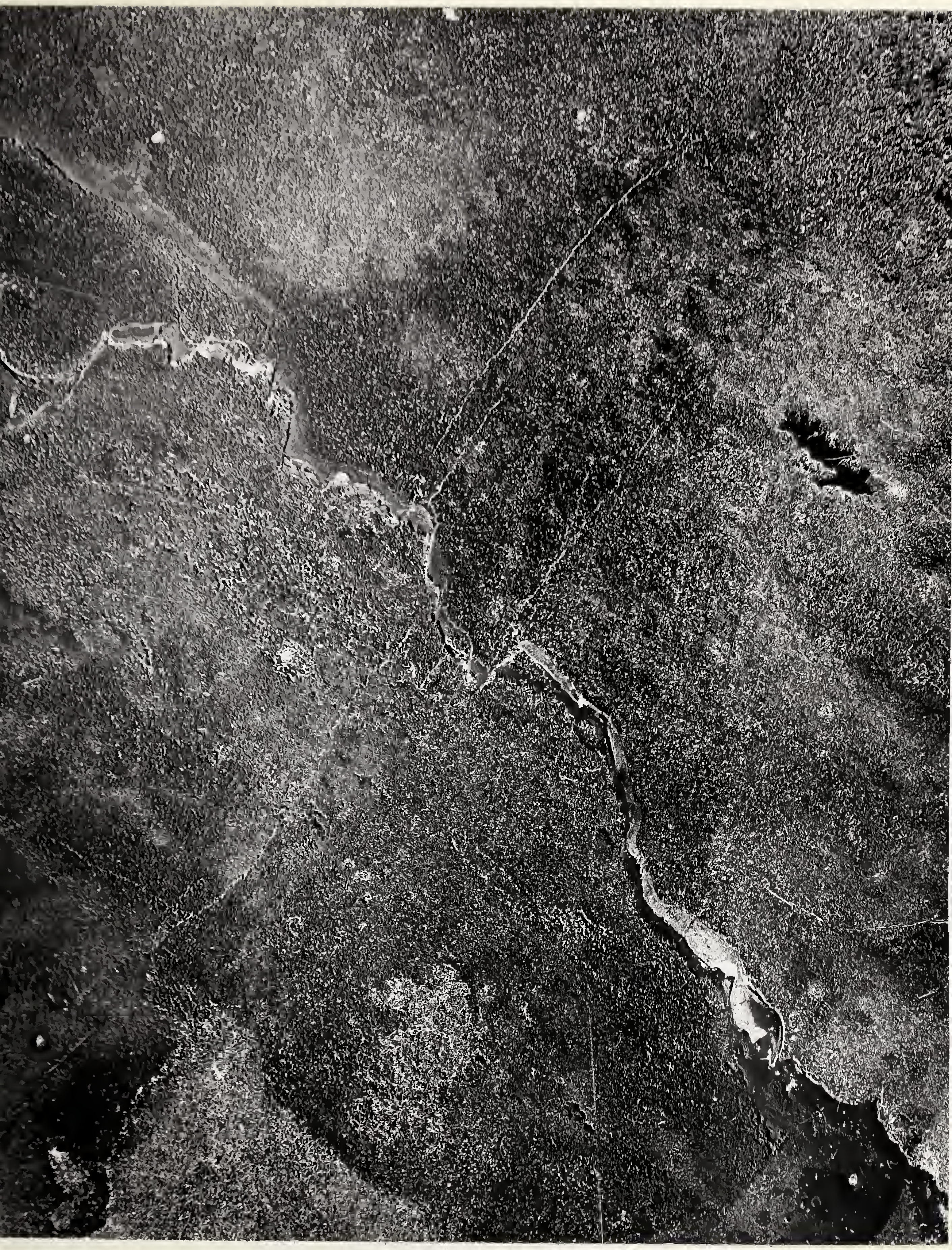
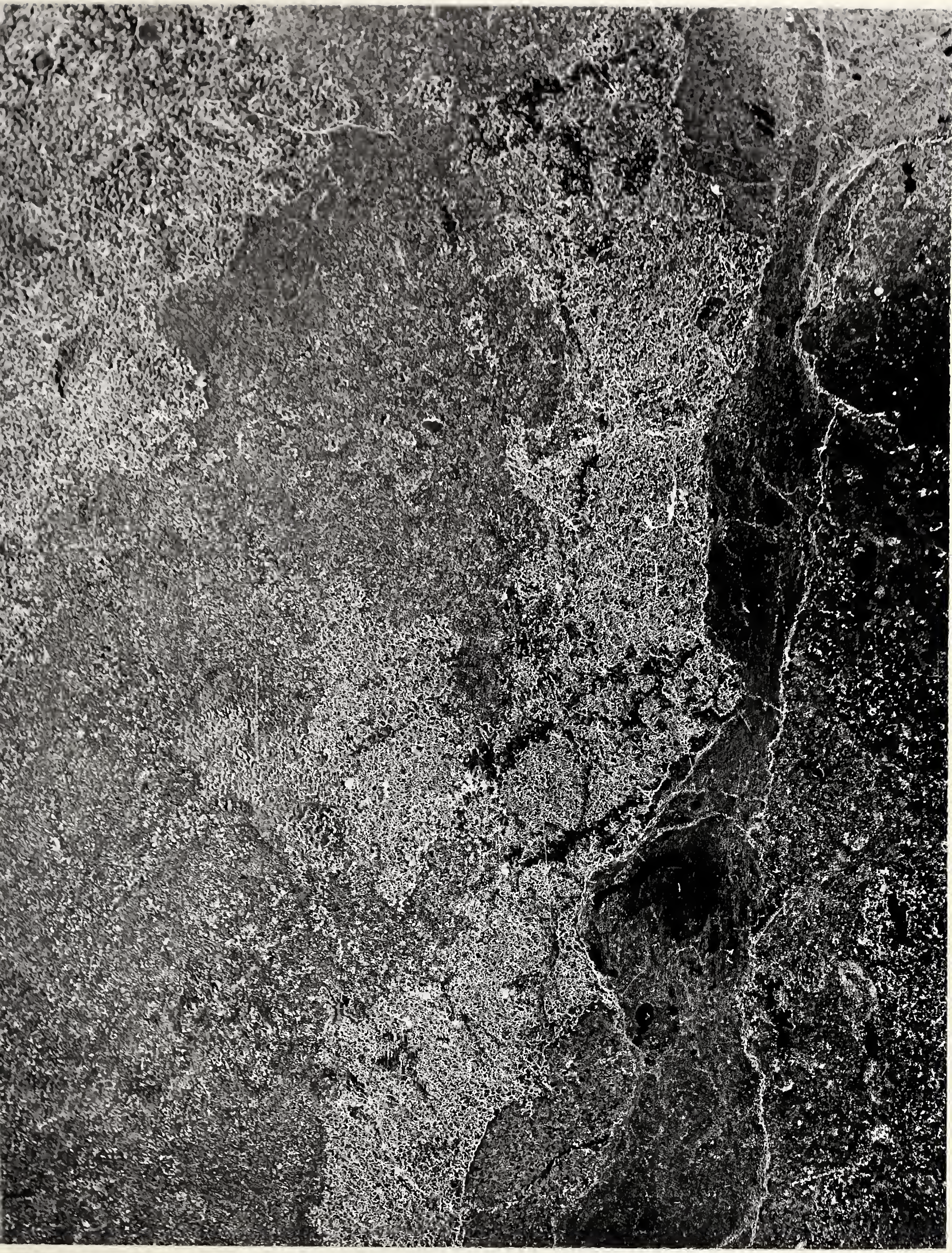


Plate 4

PLATE 5

NISKU

A 3 to 5 mm band of shale in fine to medium grained dolomite. Organic development has increased intergranular porosity. Depth 4,439 feet. X4



Top

Plate 5

PLATE 6

NISKU

Interbedded dolomite and shale. The fine-grained dark shaly bands grade into relatively coarse grained bands of re-crystallized dolomite, giving an appearance of graded bedding. Horizontal fractures are present along the contact of dolomite and shale bands. Depth 4,440 feet. X4

Top

Plate 6

PLATE 7

NISKU

Fine to medium grained dolomite, showing vuggy and intergranular porosity. Algal pellets have given a somewhat mottled appearance to the sample. Crenulated stylolite seen along the algal growth in the centre of the plate. Depth 4,450.7 feet. X4

Plate 7

Top

PLATE 8

NISKU

Organic development in Nisku dolomite. Argillaceous and dolomitic portions (lower half of the photograph) of the sample are fine grained and compact. Organic portions have developed solution cavities and vugs. Crystals of secondary calcite can be seen in some of the vugs. Depth 4461.7 feet. X4

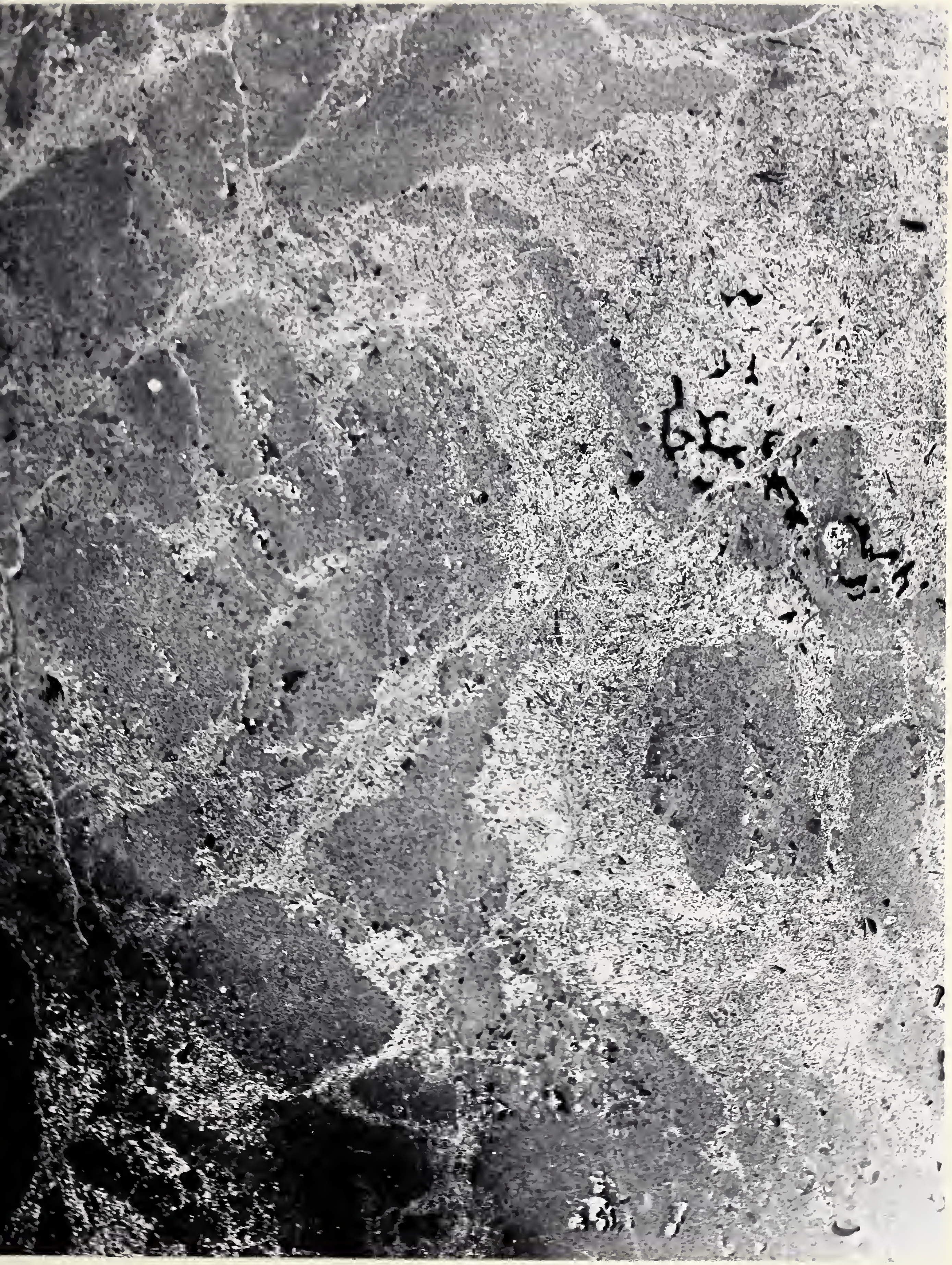
Plate 8

Top

PLATE 9

NISKU

Secondary anhydrite filling and algal development in the lower portion of the Nisku formation. Metasomatic replacement by anhydrite has given the sample a pseudo-brecciated or pelletoid appearance. The dark coloured patches in the photograph are algal pellets, and the lighter patches are anhydrite. Depth 4537.9 feet. X4



Top

Plate 9

PLATE 10

LEDUC

(a) Top portion of Leduc formation. Its reefal character is evident from the abundance of corals--mostly *Thamnopora*--and algae. Irregular positioning of the corals is suggestive of highly agitated water conditions. The algal pellets can be identified in the plate by denser and uniform texture. 'Algal ball' seen on the top left. Matrix is composed of partially dolomitized calcarenite. Scattered grains of secondary dolomite show euhedral outline. Besides intergranular porosity, traces of porosity are present in the fossils. Depth 4.697.4 feet. X4

(b) Same as 10(a). Oblique and transverse sections of *Thamnopora*--type coral fragments are well exhibited. X4

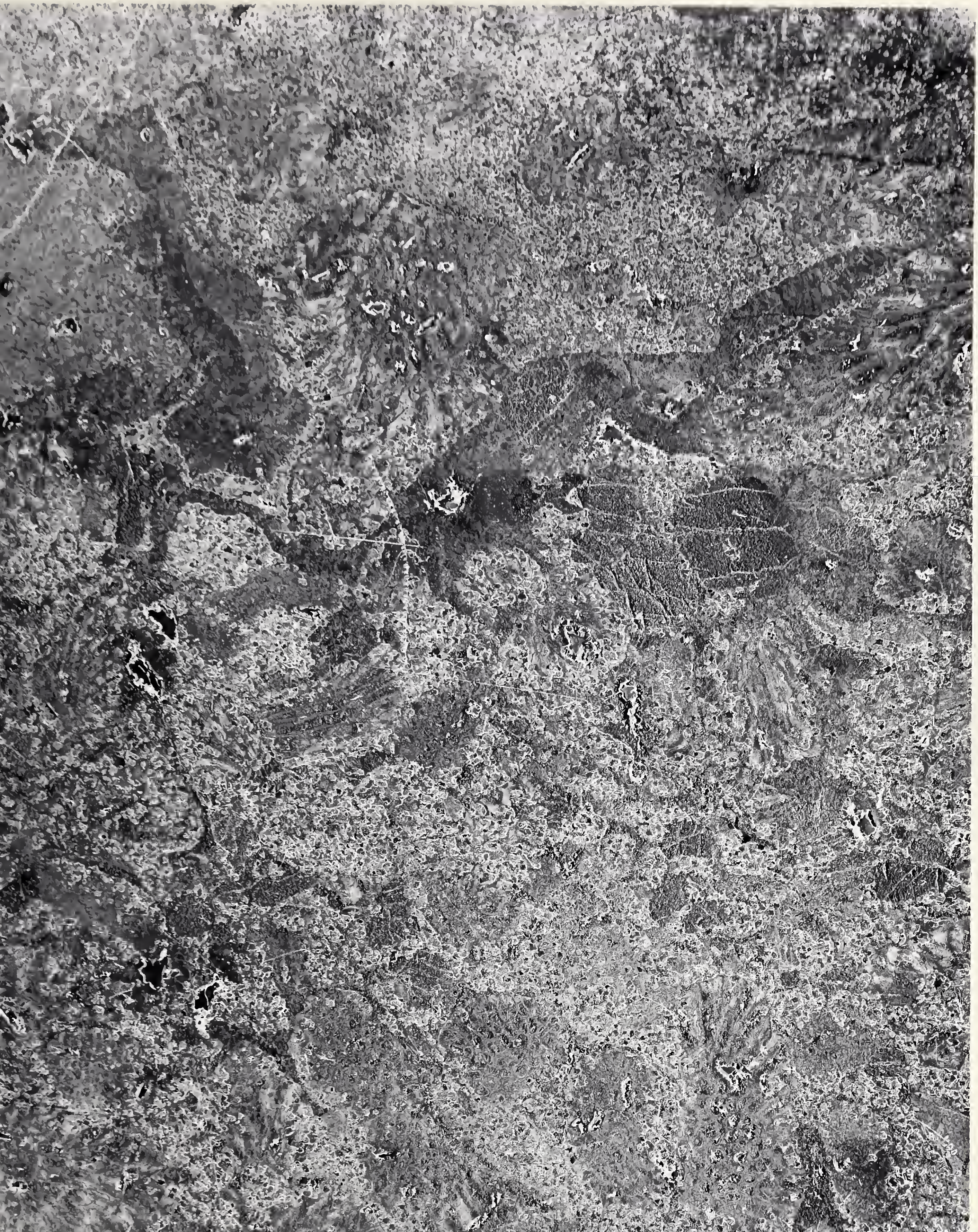


Plate 10(a)

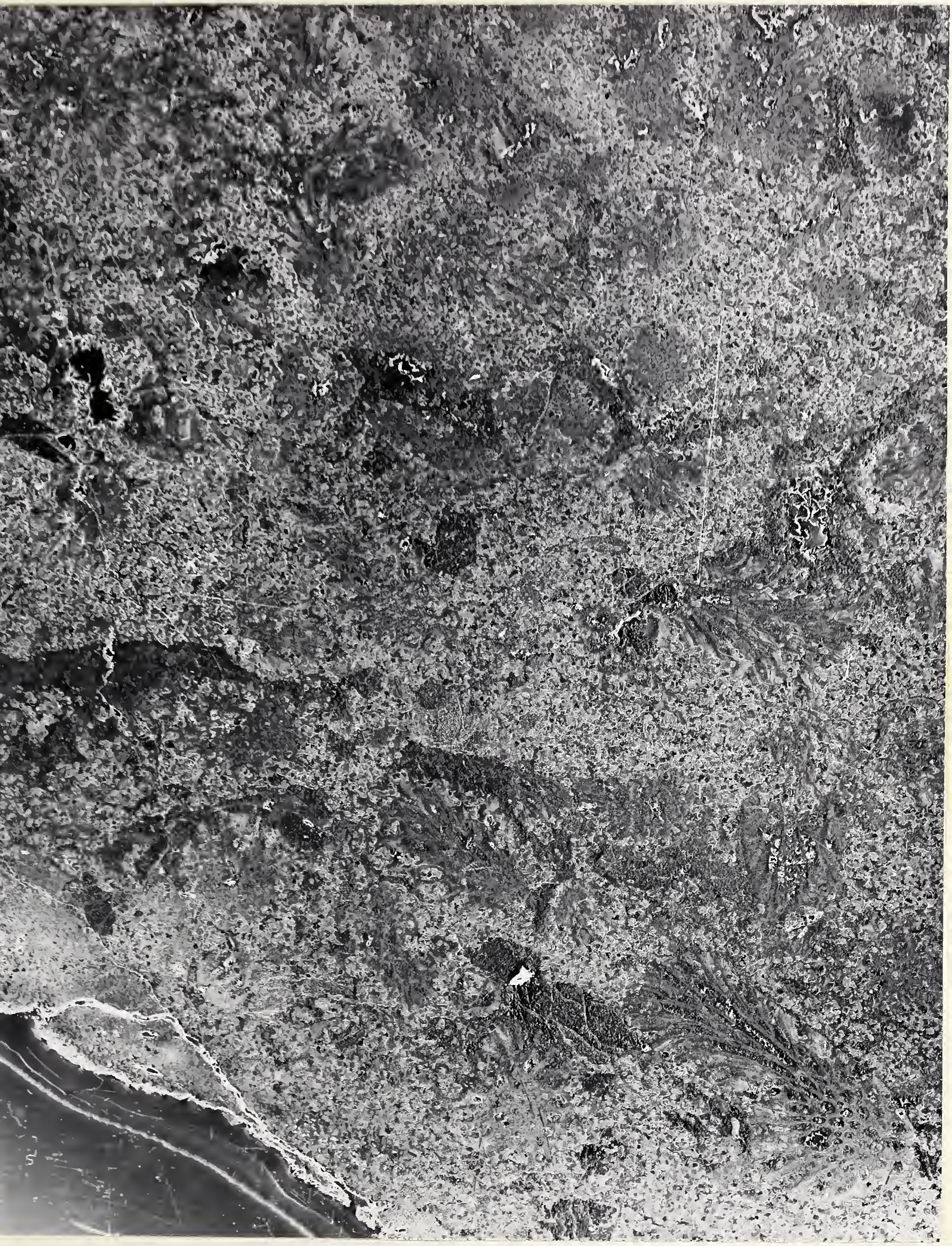


Plate 10(b)

PLATE 11

LEDUC

(a) Prolific and varied life found at the top of the Leduc formation. Oblique and near-transverse sections of the tabulate coral *Thamnopora* can be seen. Laminated stromatoporoid with "pillar structure" can be seen at the top right and centre left of the plate. Fragment of a brachiopod shell is preserved near the centre of the plate. Matrix is mainly fine grained skeletal calcirudite. Depth 4,706 feet. X4

(b) Laminated stromatoporoids with "pillar structure" and tabulate corals in fine to medium calcirudite matrix. Matrix is composed of ill sorted algal pellets and other fossil debris. Horizontal fractures have developed along some of the stromatoporoid laminae. Organic and intergranular porosity is apparent. Depth 4,706 feet. X4

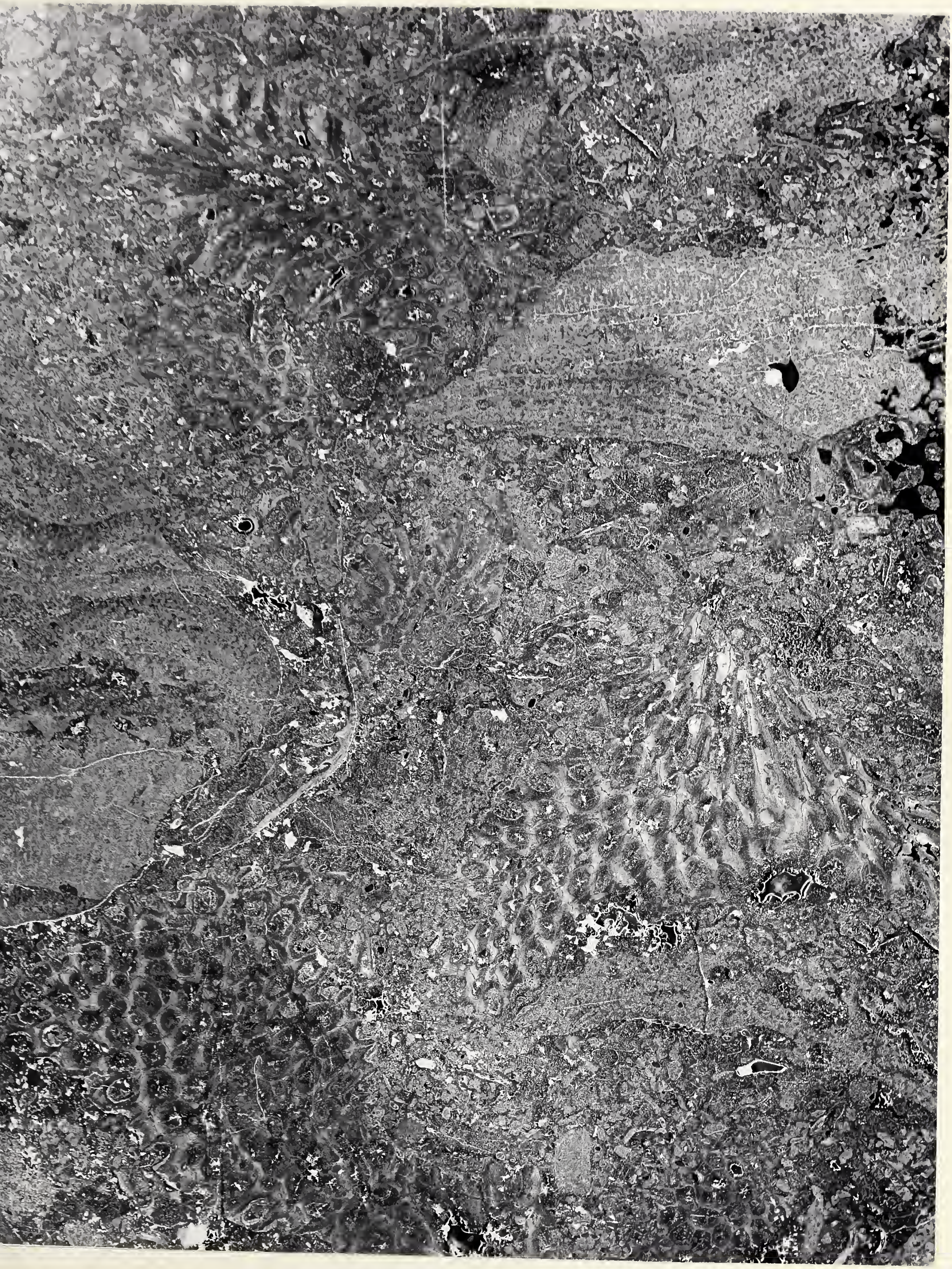


Plate 11(a)

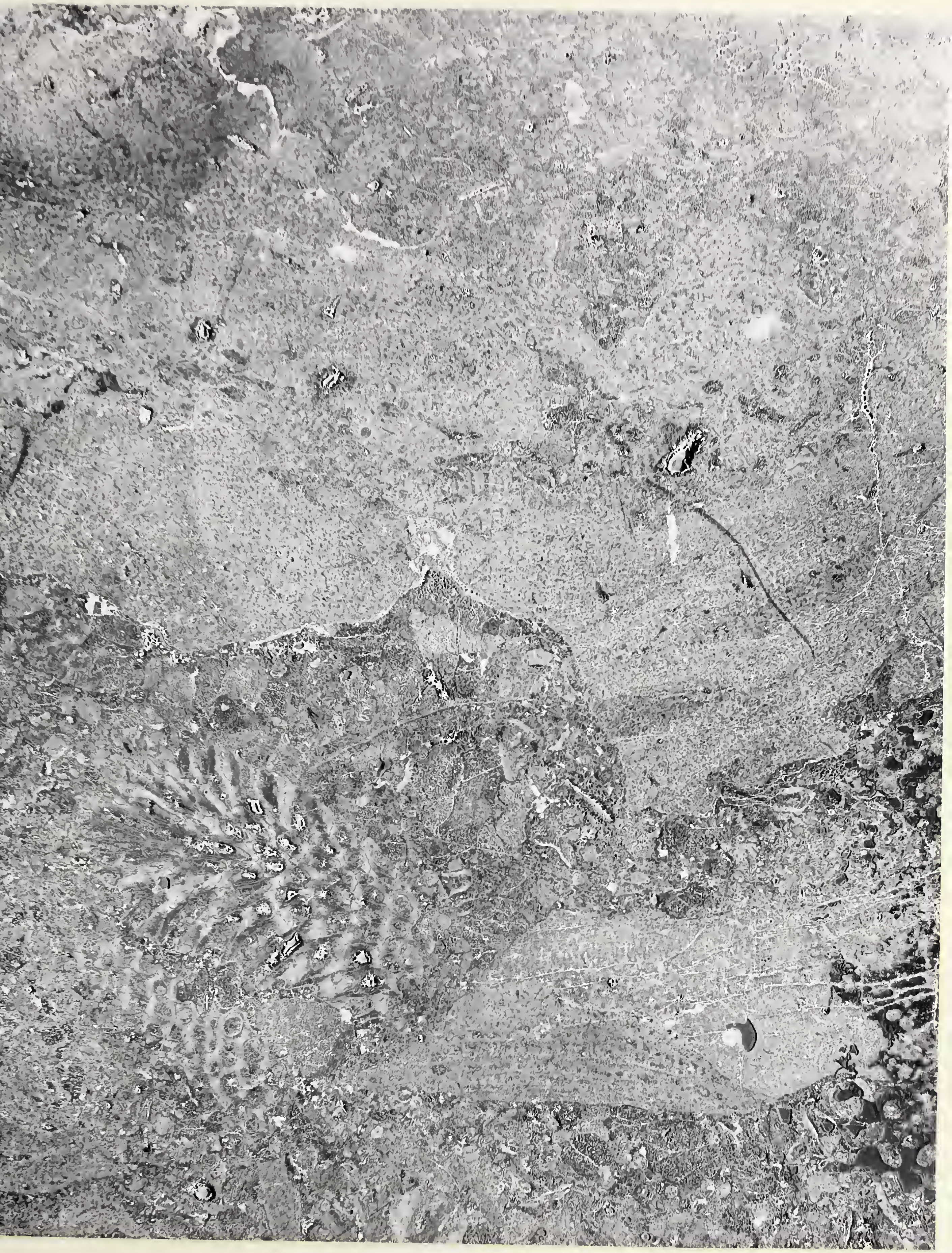


Plate 11(b)

PLATE 12

LEDUC

(a) Great variety of biohermal reef-building organisms, including stromatoporoids, algae and corals in fine to medium calcirudite matrix. Laminated stromatoporoids with "pillar-structure" exhibit reticulate meshwork pattern. Corals are tabulate type, algal pellets (right centre) are devoid of laminae or pillars. Fragment of a brachiopod shell seen near the top of the stromatoporoid fragment (top right). Depth 4,709 feet. X4

(b) Same as plate 3(a). Irregularly displaced fragments of corals and stromatoporoids suggest highly agitated water conditions. Depth 4,709 feet. X4

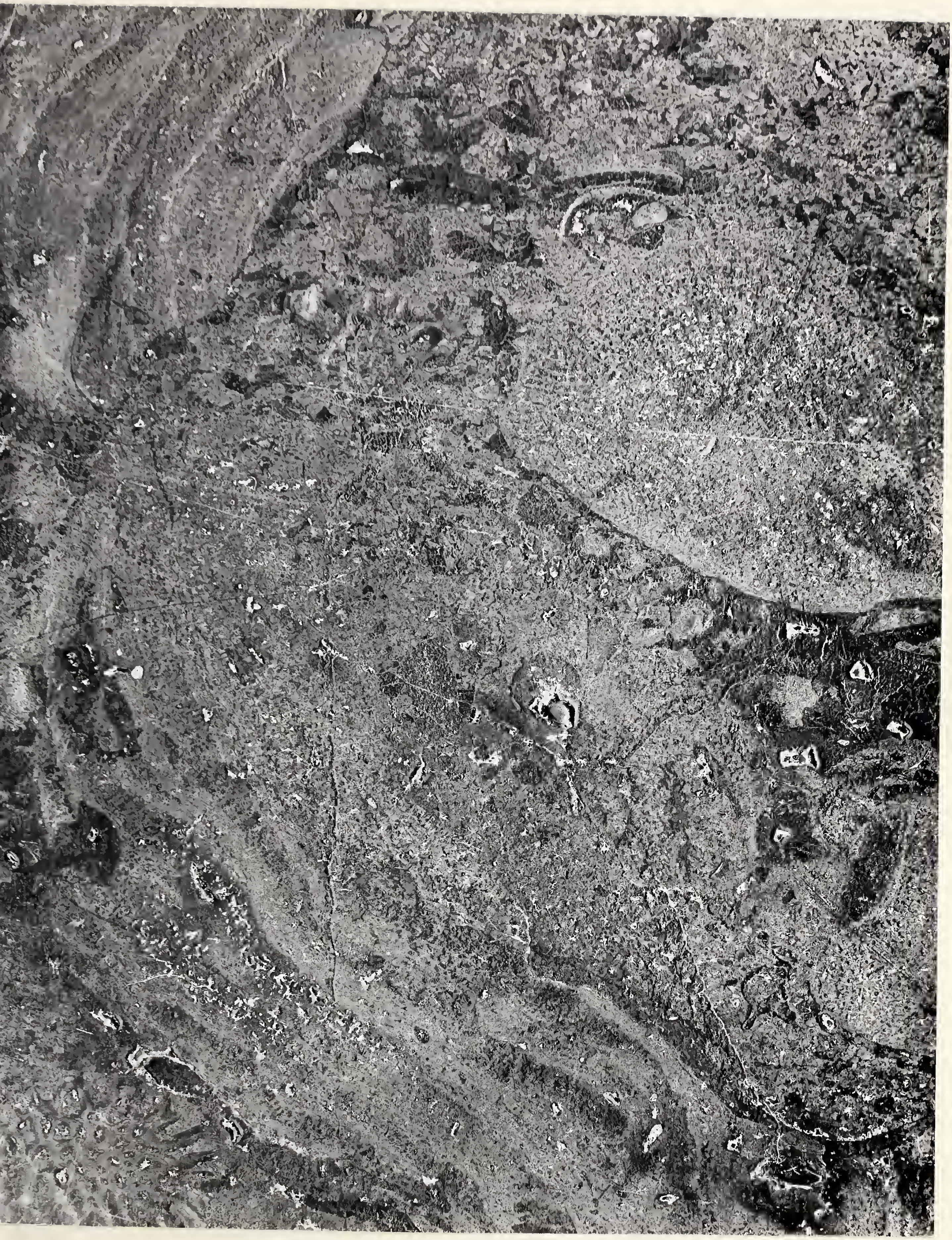


Plate 12(a)

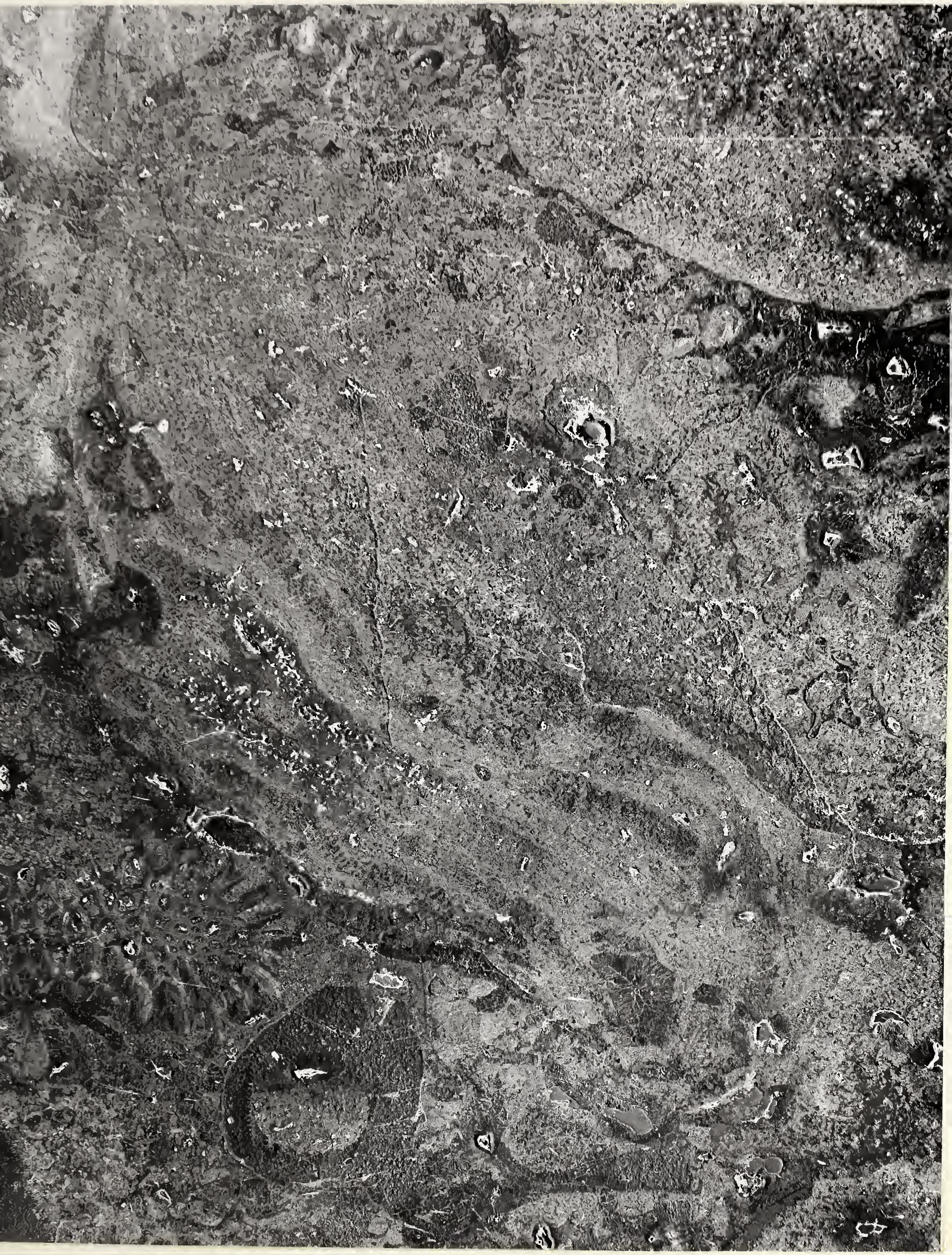


Plate 12(b)

PLATE 13

LEDUC

(a) Laminated stromatoporoids with 'pillar-structure' and algal pellets in fine to medium skeletal calcirudite matrix. Slightly vuggy, interfragmental and organic porosity evident. Depth 4,710 feet. X4

(b) Same as plate 4(a). Stromatoporoid shows finely spaced laminae with 'pillars'. Solution cavities developed along stromatoporoid laminae giving rise to high porosity. Depth 4,710 feet. X4.

Plate 13(a)

Plate 13(b)

PLATE 14

LEDUC

(a) 'Pancake'-shaped stromatoporoid showing fine, regular laminae with 'pillar structure'. Section of a rugose coral seen near left centre of the plate. Matrix is composed of fine to medium calcirudite which includes algal pellets and other fossil fragments. Vuggy and intra-fragmental porosity is apparent. Depth 4,711.8 feet. X4

(b) Large, finely laminated stromatoporoid. Detailed structure unidentifiable due to recrystallization. Tabulate coral seen near bottom right of the plate. Fine to medium bioclastic calcirudite matrix includes fragments of stromatoporoids and algal pellets. Sorting is poor. Interfragmental and slightly vuggy porosity. Depth 4,711.8 feet. X4

Plate 14(a)

Plate 14(b)

PLATE 15

LEDUC

(a) Laminated stromatoporoid with pillar structure is seen near the bottom of the plate; recyrstallization has obliterated much of the structural detail. Isolated fragments of tabulate corals can also be identified. Matrix is composed of ill sorted, very coarse calcarenite and fine calcirudite. Depth 4,723.3 feet. X4

(b) Very coarse, bioclastic calcarenite matrix. Stromatoporoid shows poorly preserved laminated structure. The dark patches on the left of the plate are marks from the acetate-peel. Depth 4,723.3 feet. X8

Top

Plate 15(a)

Plate 15(b)

PLATE 16

LEDUC

Recrystallization has obliterated the structure of the stromatoporoid, seen at the bottom of the plate. Matrix is composed of bioclastic fine calcirudite and very coarse calcarenite. Calcite from shell fragments occurs as irregular rounded pellets. Depth 4,760.6 feet. X4

Top

Plate 16

PLATE 17

LEDUC

Large, laminated stromatoporoid developed across the top of the sample; recrystallization has destroyed the 'pillar structure'. Coarse, bioclastic calcirudite matrix is composed of fragments of stromatoporoids, algae, coral and other shell material. Very good vuggy and intergranular porosity. Depth 4,763 feet.

X4

Top

Plate 17

PLATE 18

LEDUC

Large number of stromatoporoid and tabulate coral (Thamnopora) fragments associated with medium to coarse calcarenite. Irregular arrangement of corals and stromatoporoid fragments indicative of highly agitated water conditions. Good vuggy porosity. Depth, 4,771 feet. X4

Top

Plate 18

PLATE 19

LEDUC

Large, laminated stromatoporoid associated with coarse, bioclastic calcirudite matrix. Detailed features obliterated due to recrystallization. Excellent vuggy and interfragmental porosity. Depth 4,771.8 feet. X4

Top

Plate 19

PLATE 20

LEDUC

(a) Large, laminated stromatoporoid associated with poorly sorted, coarse, bioclastic calcirudite. Excellent vuggy and interfragmental porosity. Solution cavities developed along stromatoporoid laminae. Depth 4,786.7 feet. X5

(b) Top half of the plate shows medium to coarse, bioclastic calcarenite matrix with traces of vuggy porosity. Lower half of the plate shows coarse calcirudite, composed of stromatoporoid and other fossil fragments. Excellent vuggy porosity. Depth 4,786.7 feet. X4

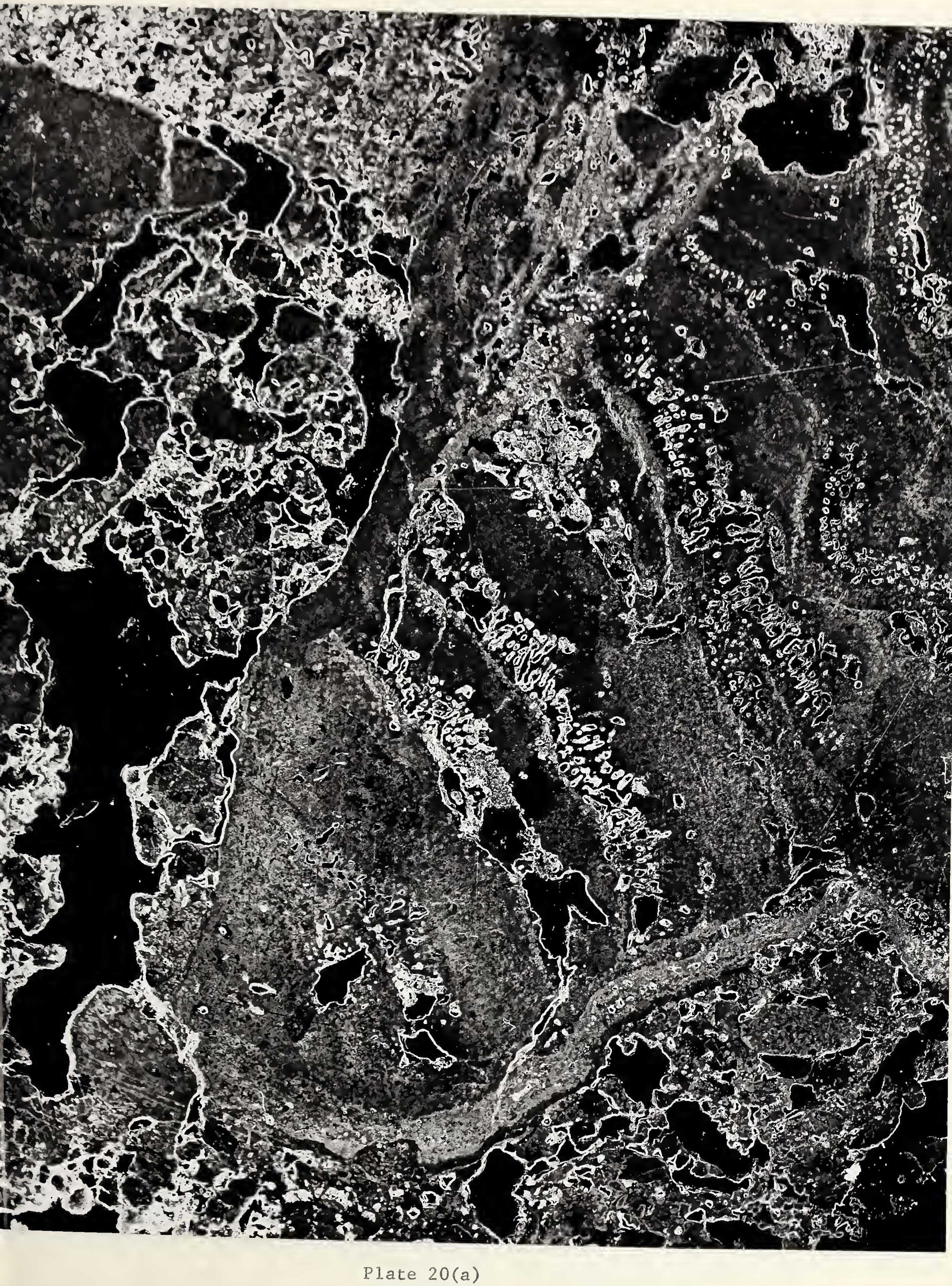


Plate 20(a)

Plate 20(b)

PLATE 21

LEDUC

Sections of coral Alveolites. Section cuts some corallites longitudinally and some transversely. Corallites seem to grow obliquely from one or more centres of growth, mainly parallel to the axis of the branch. This type of growth seems to be a very characteristic and consistent feature. Depth 4794.7 feet. X4

Top

Plate 21

PLATE 22

LEDUC

Magnificent longitudinal section of a tabulate coral displayed amidst calcirudite matrix. Algal development seen near top left of the plate. Matrix also includes algal pellet and fragments of corals. Very good vuggy and intergranular porosity. Depth 4796.5 feet. X4

Top

Plate 22

PLATE 23

LEDUC

Poorly sorted, bioclastic, coarse calcarenite and calcirudite matrix. Rhombic cleavage very well exhibited in calcite grains. Transverse section of a tabulate coral seen near bottom centre of the plate. Good intergranular and vuggy porosity. Depth 4,821 feet. X5

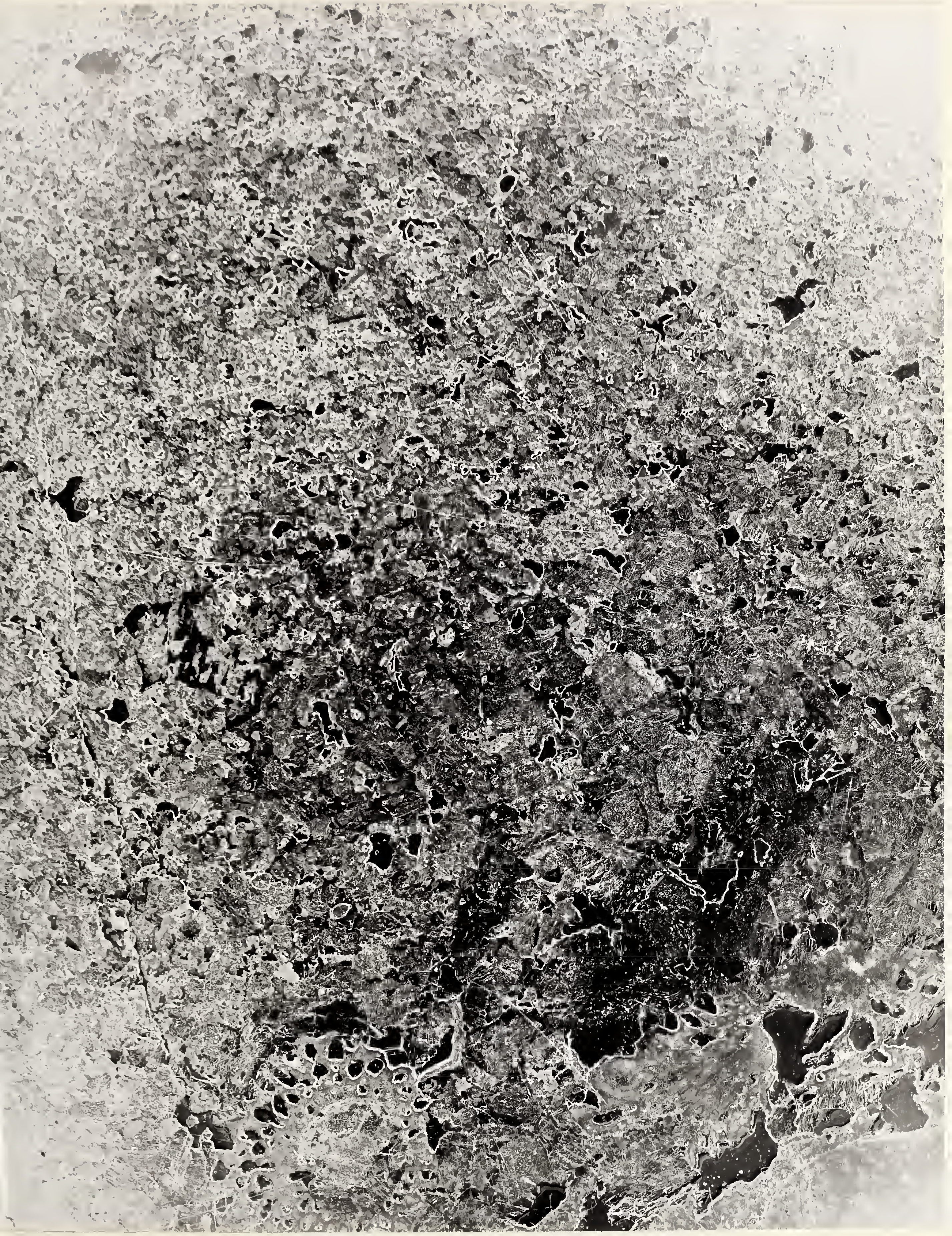
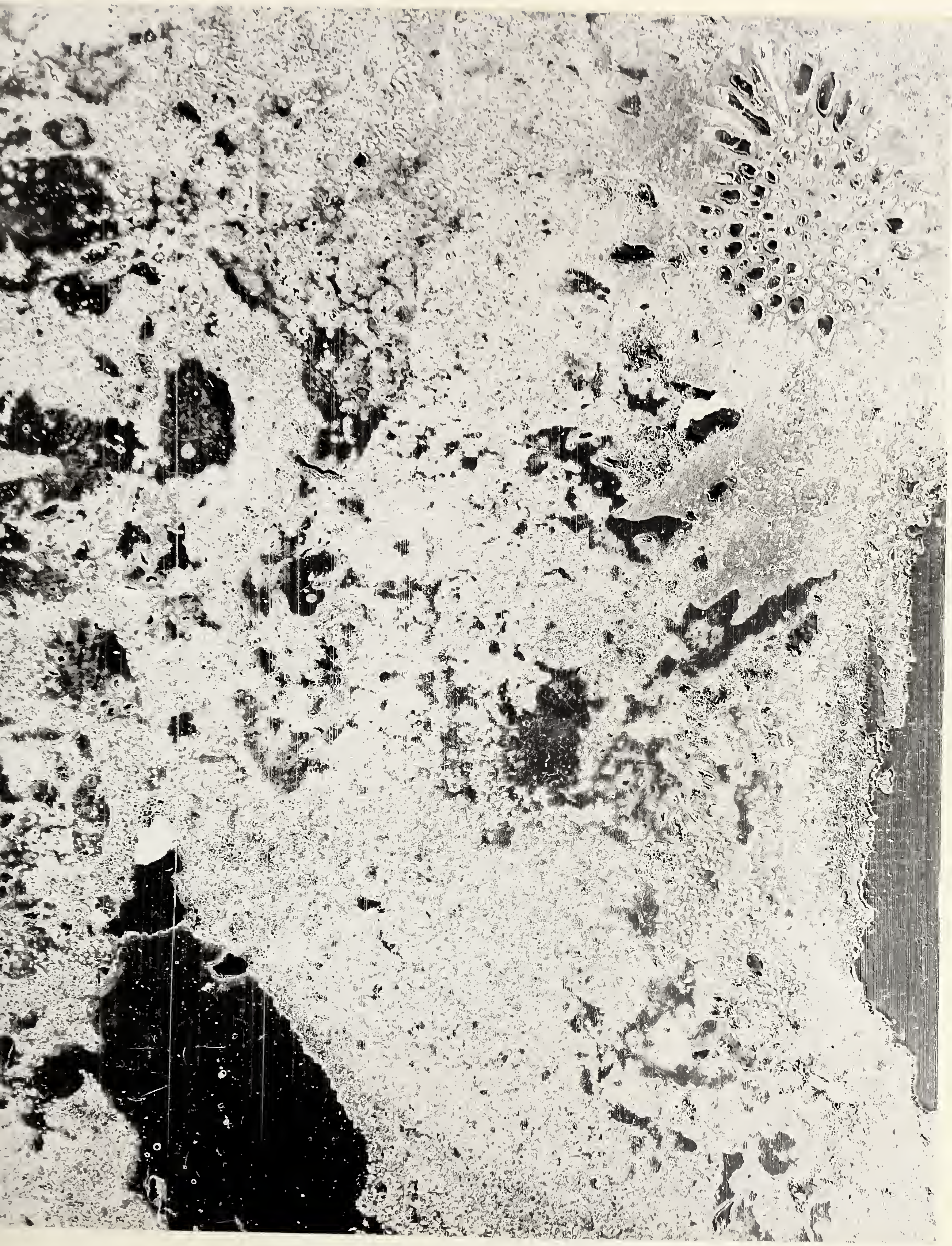


Plate 23

PLATE 24

LEDUC

Lower part of the plate shows transverse sections of several corals along with some algal material. Fragments of poorly preserved, recrystallized stromatoporoids can be seen near the top of the plate. Matrix is mostly calcarenite. Traces of vuggy and intergranular porosity. Depth 4,833.4 feet. X4



Top

Plate 24

PLATE 25

LEDUC

Recrystallized stromatoporoid in calcarenite matrix. Isolated fragments of algae and corals included in the matrix. Some of the vugs longer than one centimetre. Depth 4,835.5 feet. X4

Top

Plate 25

PLATE 26

LEDUC

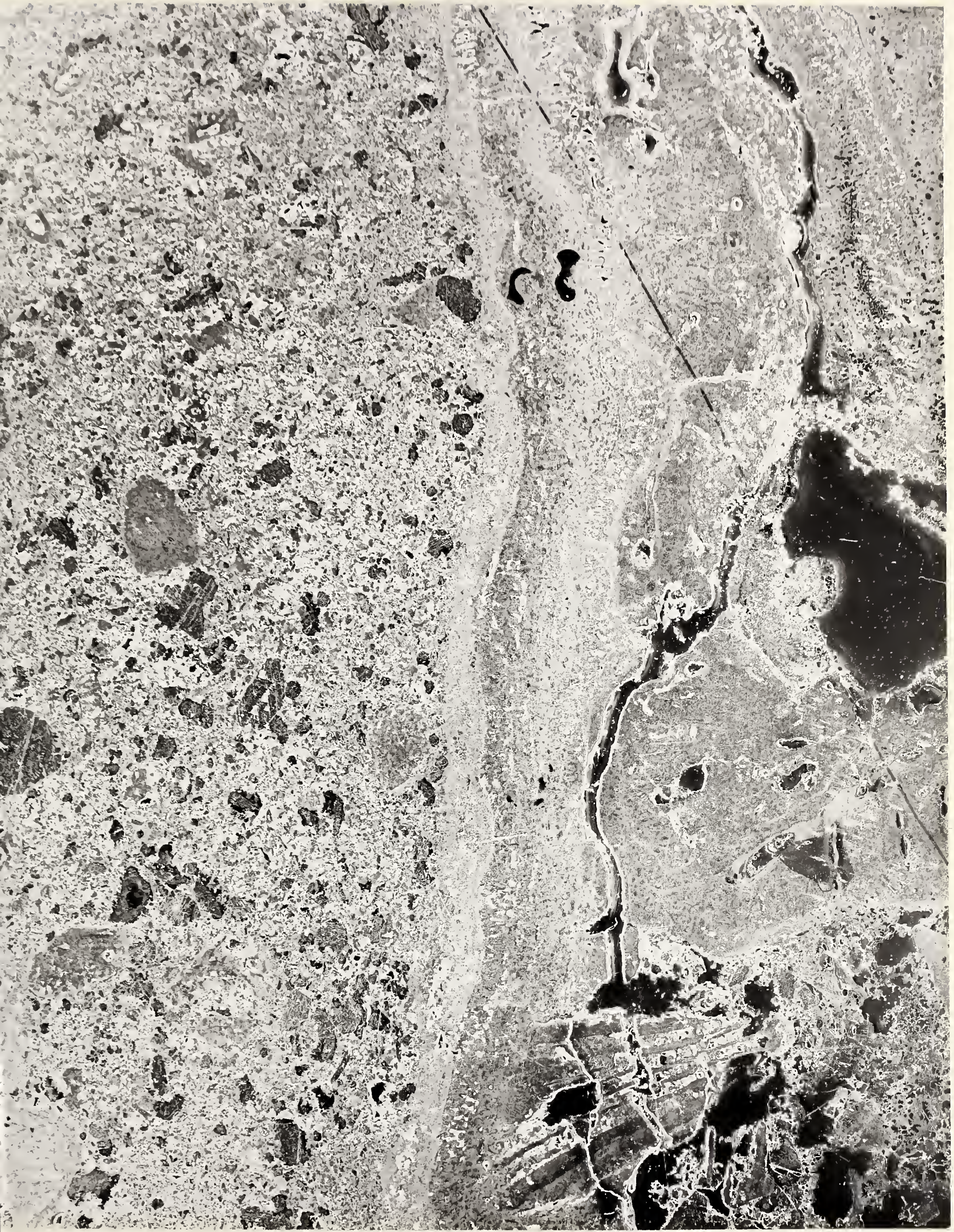
Matrix is composed of coarse, bioclastic calcarenite. Some of the algal pellets in the matrix greater than 5 mm in diameter. A poorly preserved, recrystallized stromatoporoid on the right edge of the sample. Good vuggy and intergranular porosity. Depth 4,839 feet. X4

Plate 26

PLATE 27

LEDUC

Lower part of the plate shows a poorly preserved, laminated stromatoporoid. Fragment of a coral seen near left bottom of the plate. Matrix is fine calcirudite with scattered algal pellets and shell fragments. Good intergranular porosity. Depth 4,843 feet. X4



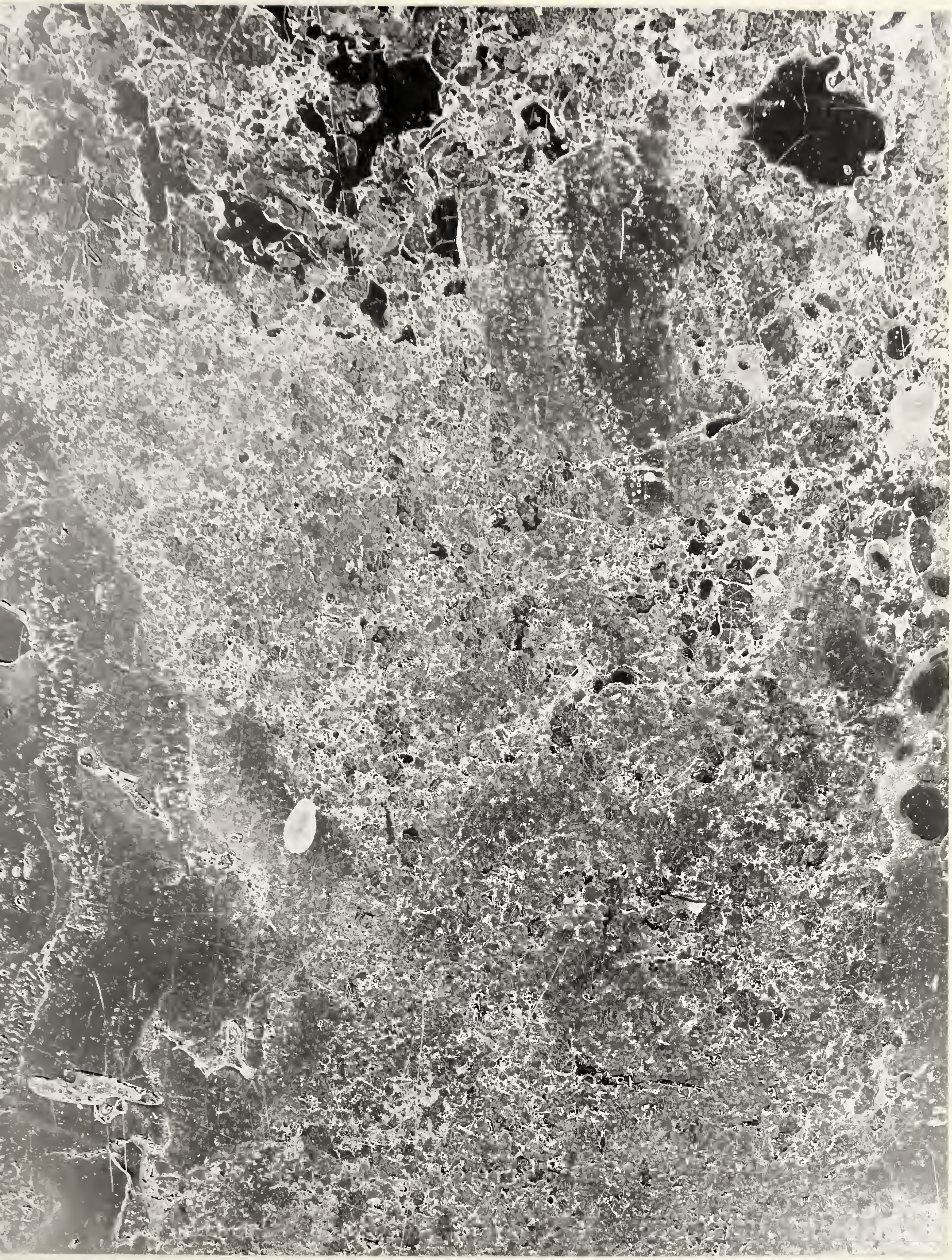
Top

Plate 27

PLATE 28

LEDUC

Poorly sorted, coarse, bioclastic calcirudite. Fragments of stromatoporoid show laminated structure. Abrupt trancation of the stromatoporoid (right centre) suggest highly agitated water conditions. Excellent vuggy and intergranular porosity. Depth 4,848 feet. X4



Top

Plate 28

PLATE 29

LEDUC

Well sorted, bioclastic calcirudite matrix. Larger grains of calcite show rhombic cleavage. The organic form in the centre is most probably a stromatoporoid whose structural features have been obliterated by recrystallization. Depth 4,850.8 feet. X4

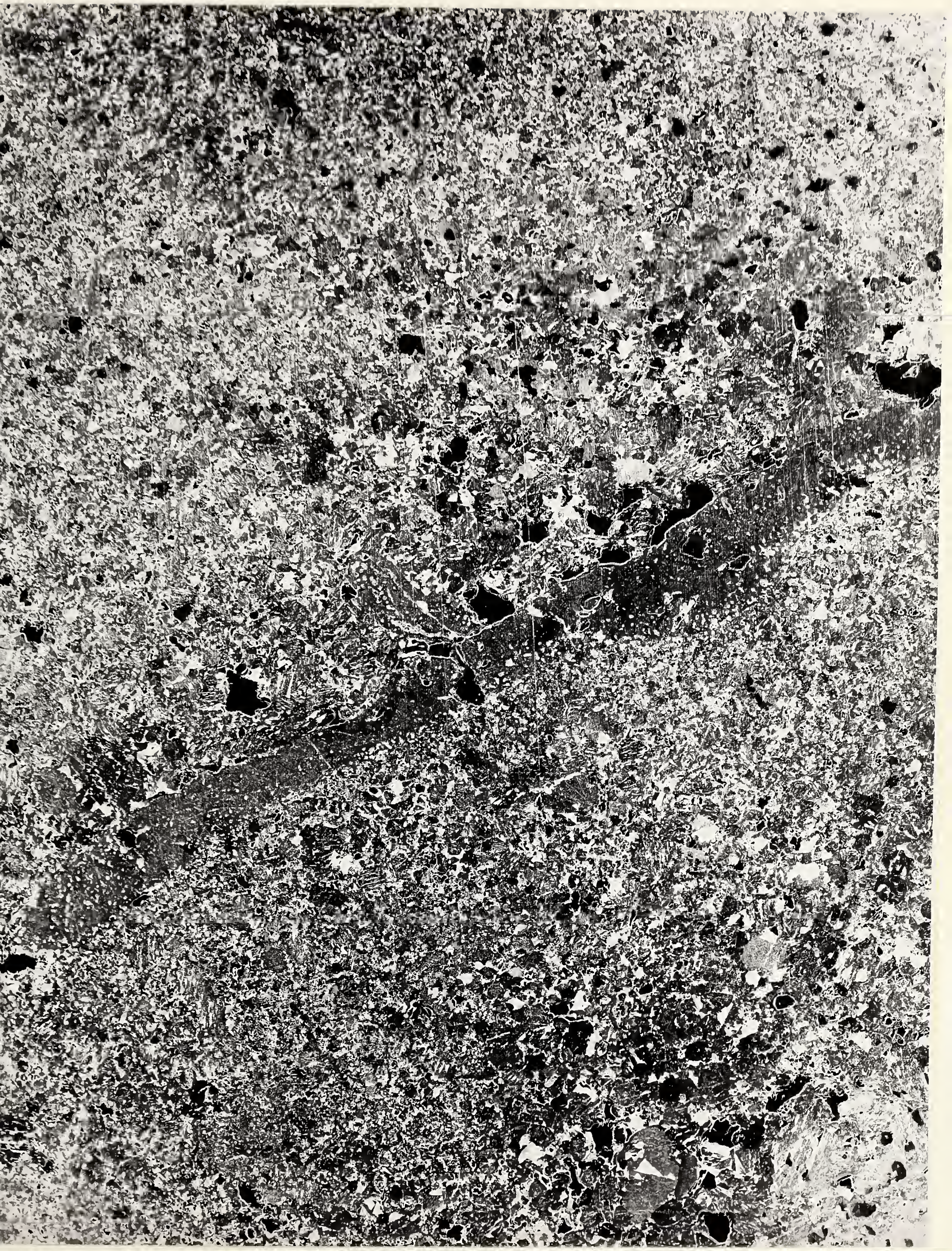


Plate 29

PLATE 30

LEDUC

Laminated stromatoporoids with 'pillar structure' in fine calcirudite matrix. Bioclastic matrix consists of algal pellets and skeletal material. Rhombic cleavage in larger calcite grains very well exhibited. Good vuggy and interfragmental porosity. Depth 4,853 feet. X4

Top

Plate 30

PLATE 31

LEDUC

Laminated stromatoporoid seen at the top portion of the plate. 'Pillar structure' seems to have been destroyed by recrystallization. Thamnopora type of coral at the bottom center of the plate. Matrix is mainly skeletal calcirudite. Excellent vuggy and interfragmental porosity. Depth 4,859 feet. X4

Top

Plate 31

PLATE 32

LEDUC

(a) Recyrstallized, coarse calcarenite matrix, with larger calcite grains showing rhombic cleavage and subangular, euhedral outline. Laminated stromatoporoid seen on the left of the plate. The stromatoporoid too has been recrystallized, thus obliterating much of the detailed structure. The organism on bottom right is probably a stromatoporoid too. Slightly vuggy and intergranular porosity. Depth 4,863 feet. X4

(b) Transverse sections of the coral Synaptophyllum (Disphyllum?) seen across the plate. Matrix is composed of recrystallized, coarse calcarenite. Depth 4,863 feet. X4

Plate 32(a)

Top

Plate 32(b)

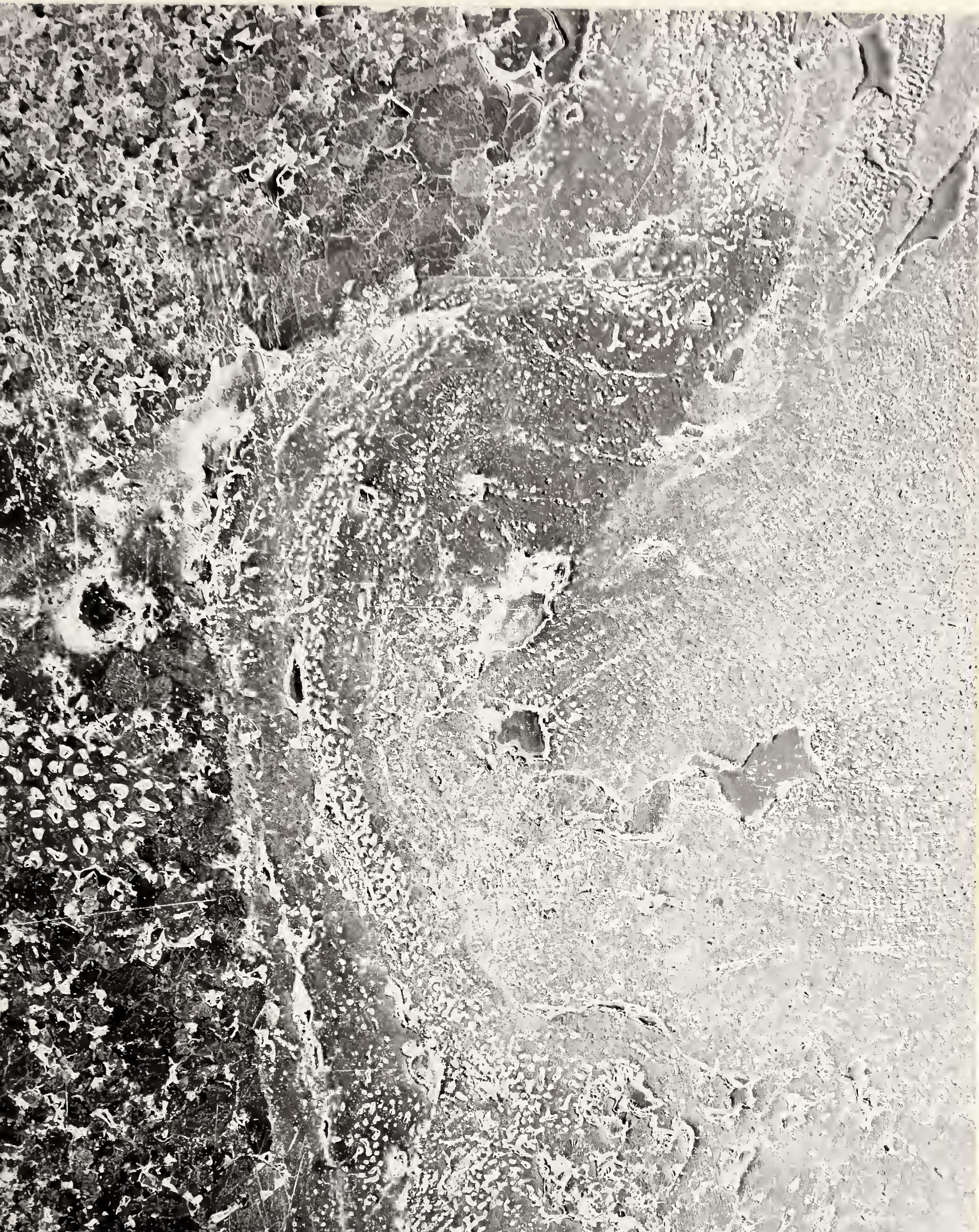
PLATE 33

LEDUC

(a) Scattered sections of Thamnopora-type corals. The matrix is composed of coarse calcarenite and fine calcirudite. Good intergranular and organic porosity apparent. Depth 4,868 feet. X4

(b) Large, laminated stromatoporoid showing 'pillar structure'. Transverse section of a tabulate coral seen near top center. Large calcite grains of the calcirudite matrix show rhombic cleavage. Good vuggy porosity. Depth 4,868 feet. X5

Plate 33(a)



Top

Plate 33(b)

PLATE 34

LEDUC

Laminated stromatoporoids with 'pillar structure' seen in fine calcirudite matrix. Effects of recrystallization apparent. Good vuggy and intergranular porosity. Depth 4870 feet. X4

Top

Plate 34

APPENDIX C

Description of Thin Sections

Thin Section No. 1: Calmar Formation
See Plate 35

Depth below surface: 4,409.7 feet, X10

Description:

The chief components are clay minerals, calcite and quartz. The clay minerals are brownish and have rather indefinite outlines. Irregularly laminated structure is well exhibited. The grain size varies from fine silt to clay; the calcite grains generally being the coarser. The grains are subangular to subrounded; occasionally quartz grains are angular. Pyrite is fairly abundant, occurring as minute disseminated grains or nodular aggregates; excellent euhedral crystal forms are common.

Classification: Calcareous shale.

Thin Section No. 2: Nisku Formation
See Plate 36

Depth below surface: 4450.7 feet, X10

Description:

The thin section displays a rock composed almost entirely of dolomite (greater than 90 per cent dolomite as indicated by X-ray analysis). The grain size varies from fine (1/8 mm) to medium (1/2 mm) sand, exhibiting angular to subangular texture; subrounded grains are also common. Well developed euhedral grains of dolomite are not uncommon. Accessory components are quartz and organic matter. Well developed, crenulated stylolite is filled with carbonaceous material and quartz. Porosity is 8.5 per cent.

Classification: Dolomite

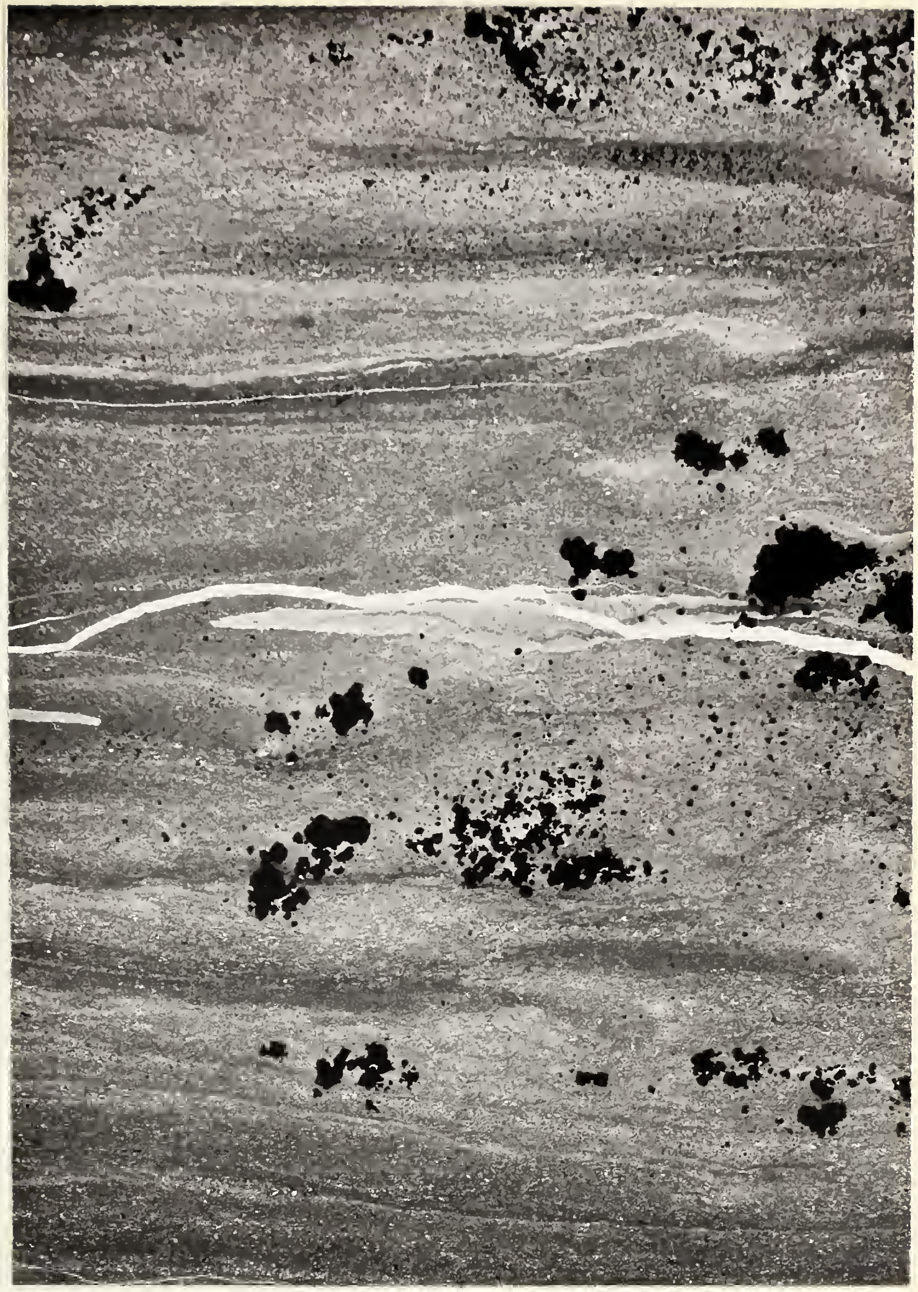


Plate 35

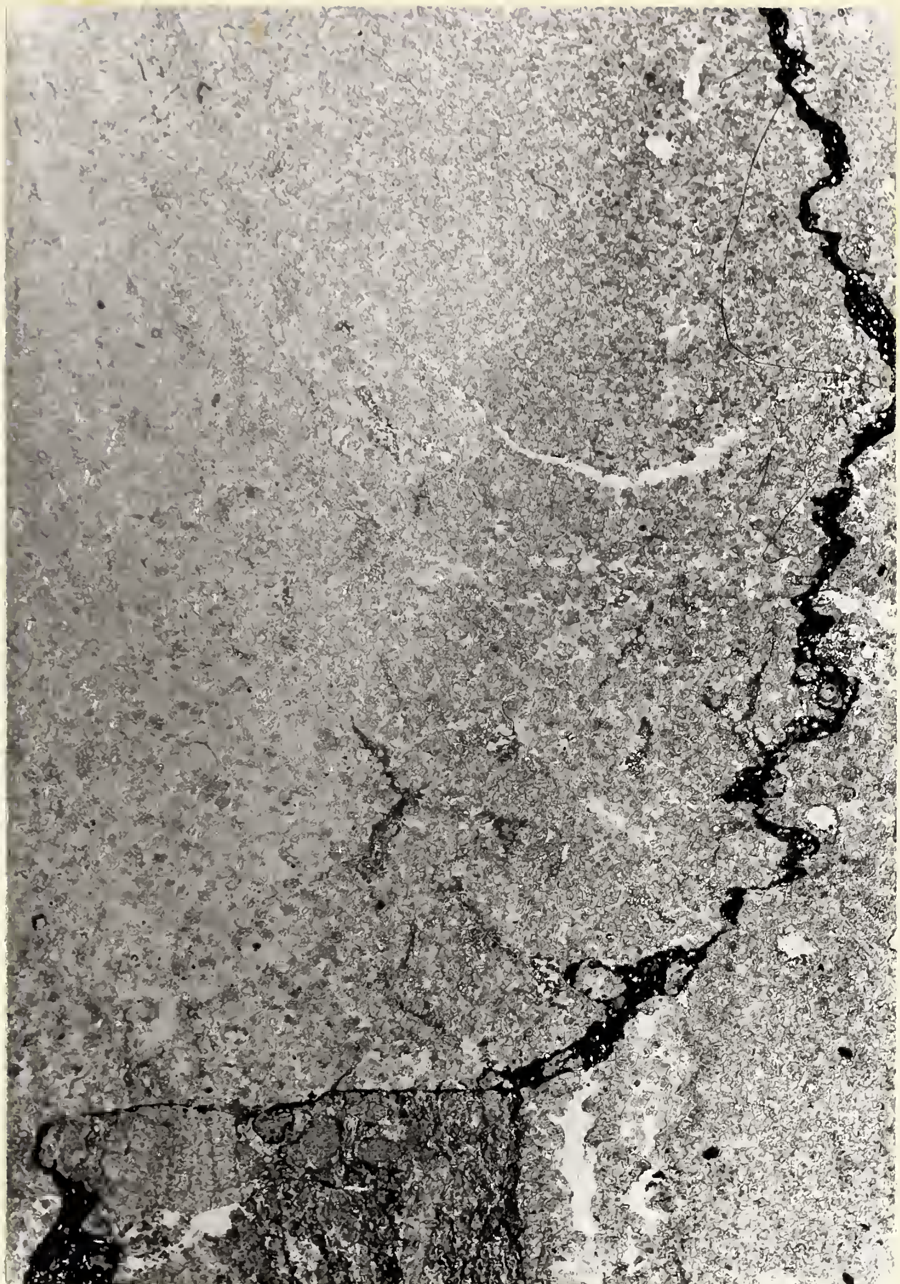


Plate 36

Thin Section No. 3: Nisku Formation
See Plate 37(a) and (b)

Depth below surface: 4518.5 feet, X10

Description:

Characteristic granoblastic texture, indicating large scale recrystallization is well displayed. X-ray analysis indicated greater than 90 per cent dolomite. Grain size is medium to coarse sand (1/4 mm to 1 mm), most of the grains being angular to subangular and are interlocked in a uniform mozaic. Many of the dolomite crystals tend to show euhedral form. Zoning of the dolomite rhombs is a very important feature. The central portion is clouded whereas the peripheral part is clear. In some cases the diagenetic overgrowth has developed parallel to the rhomb whereas in some grains the overgrowth is irregular. This phenomenon represents two stages of dolomitization, the first phase being the replacement of the original calcite grain, and the second phase being the diagenetic development around it.

Anhydrite and carbonaceous material occur as accessory minerals. Porosity is about 14.7 per cent, developed by solution cavities and vugs.

Classification: Dolomite

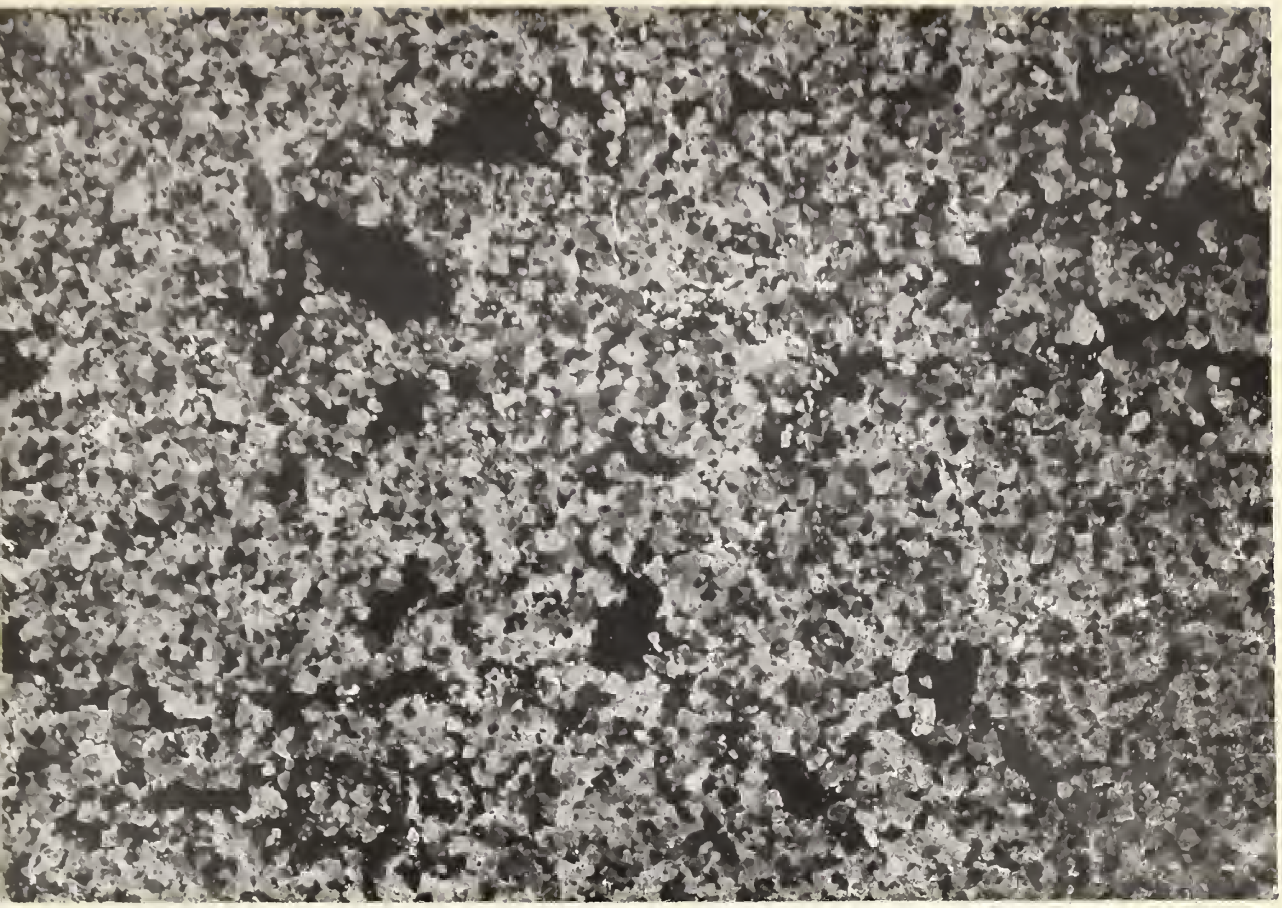
Thin Section No. 4: Ireton Formation
No plate

Depth below surface: 4695.3 feet

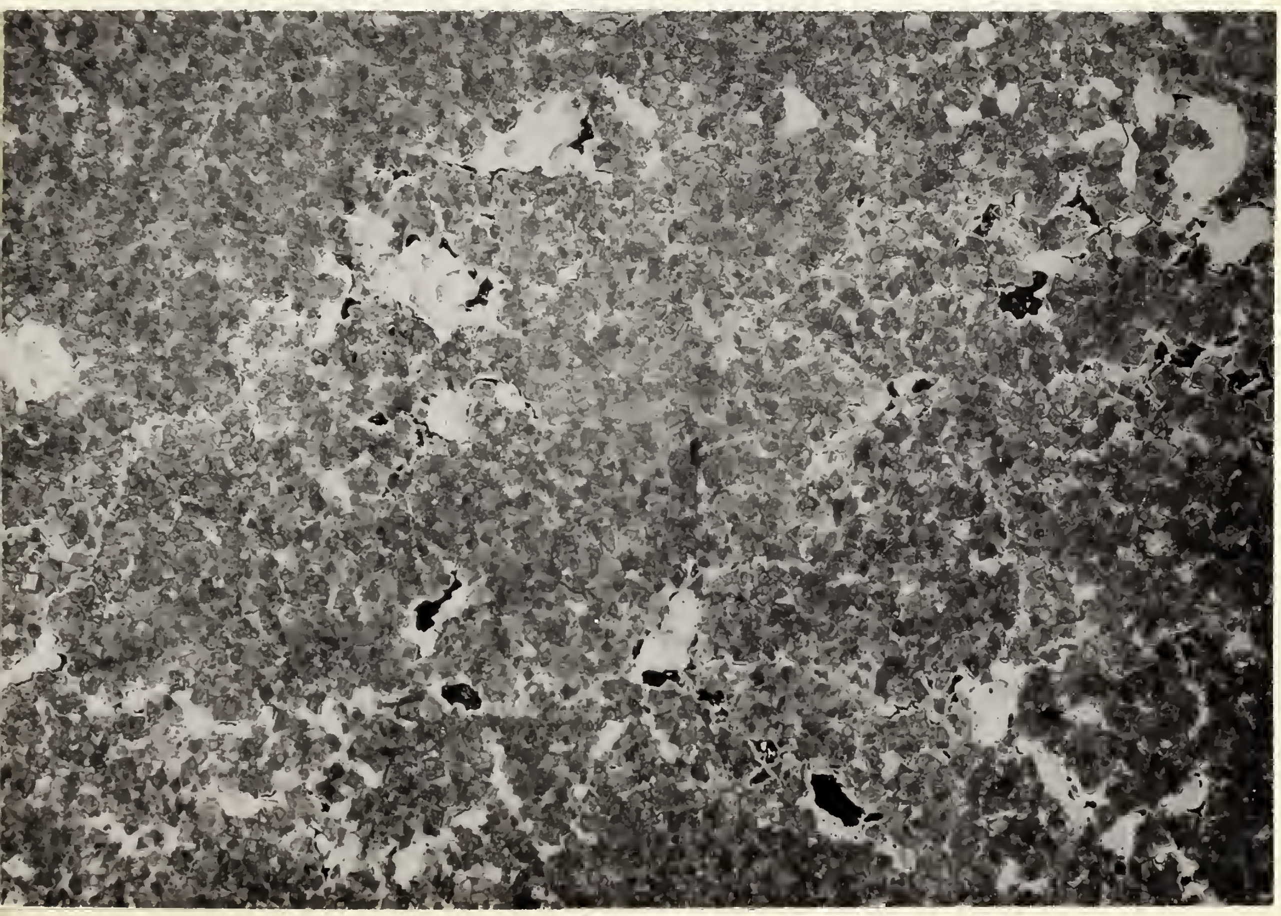
Description:

The chief constituents are clay minerals, dolomite and quartz. The clay minerals have indefinite outlines. Grains are fine clay size, subangular to subrounded. Structure is finely laminated. Pyrite is fairly abundant occurring as minute disseminated grains and aggregates; euhedral crystals are also present.

Classification: Dolomitic shale



37(b)



37(a)

Plate 37

Thin Section No. 5: Leduc Formation
See Plate 38(a)

Depth below surface: 4697.5 feet, X10

Description:

Fragments of Thamnopora-type tabulate corals in medium calcarenite matrix. Grains are angular to subangular. Scattered dolomite crystals are euhedral and angular, indicative of replacement. Euhedral crystals of anhydrite occur as fine aggregates between the coral tabulae. The tabulae are composed of fibrous calcite. X-ray analysis indicated 25 per cent dolomite.

Classification: Dolomitic bioclastic calcarenite

Thin Section No. 6: Leduc Formation
See Plate 38(b)

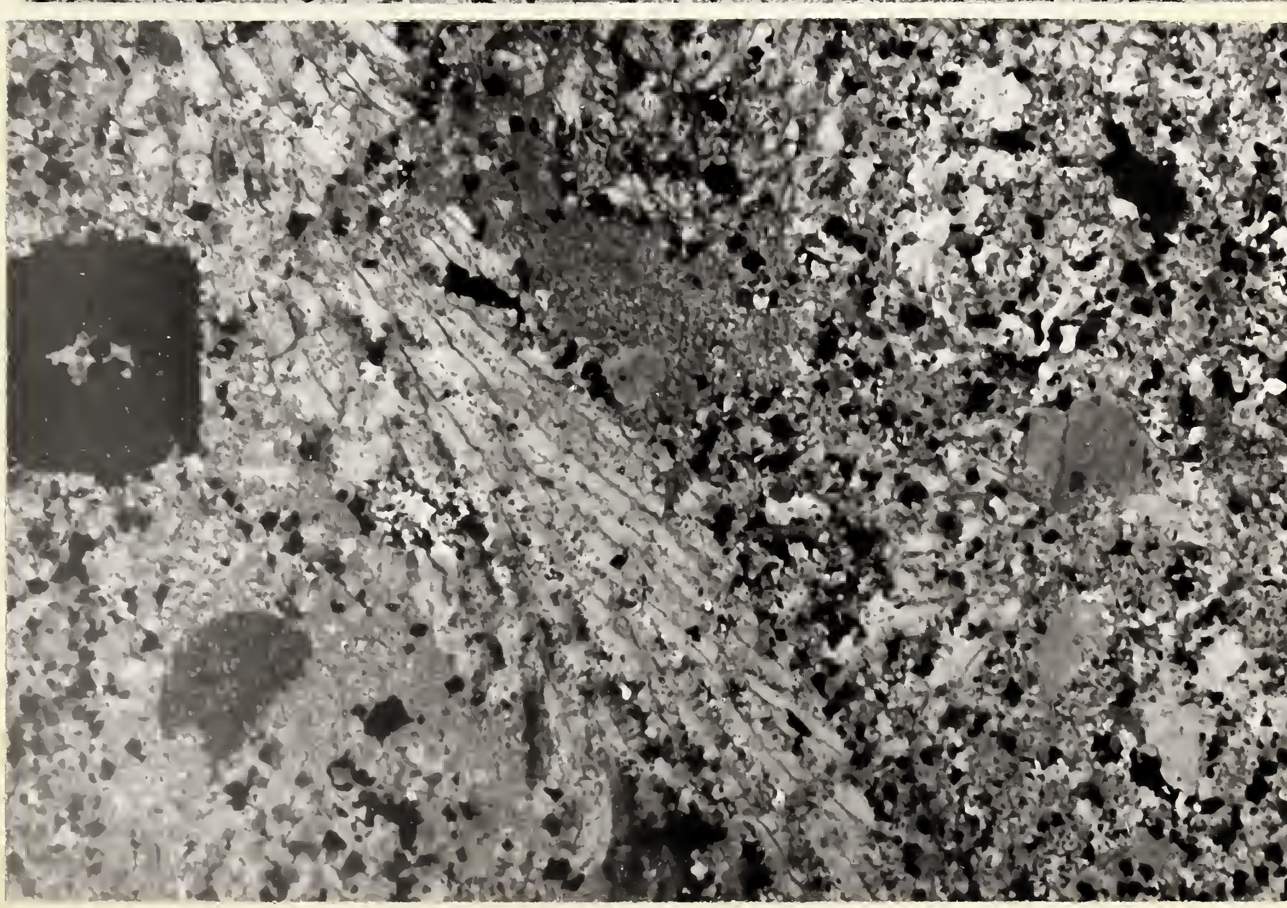
Depth below surface: 4773.3 feet, X10

Description:

Fine bioclastic calcirudite matrix is composed of fragments of tabulate corals, algae and stromatoporoids. The large organic structure might be an algae or a stromatoporoid, recrystallization has obliterated its internal features, thus making its identification impossible. Several calcite grains show effects of replacement. The central portion contains inclusions, whereas the peripheral margins are clear, thus giving the grain a zoned appearance. This indicates that the original organic material was first altered to calcite and later there was a diagenetic growth of calcite around the periphery. Some of the large crystals of calcite (greater than 2 mm) show effect of cementation around their borders. Perhaps these represent the secondary calcite crystals formed in solution cavities around which partial cementation occurred later on. However, lack of much cementation and loose packing of the matrix has produced 15 per cent porosity. X-ray analysis indicates absence of dolomite.

Classification: Bioclastic Calcirudite

38(b)



38(a)

Plate 38

Thin Section No. 7: Leduc Formation
See Plate 39(a) and (b)

Depth below surface: 4789.5 feet, X10

Description:

Fragments of laminated stromatoporoids showing pillar-structure are common. Fine bioclastic calcirudite matrix is composed of coral fragments and algal pellets; some of the calcite crystals show euhedral margins. Distinctive development of sphalerite crystals is displayed along the solution cavity. The sphalerite crystals are greyish olive in colour with purple tinge in some parts.

Porosity is 12 per cent. X-ray analysis shows complete absence of dolomite.

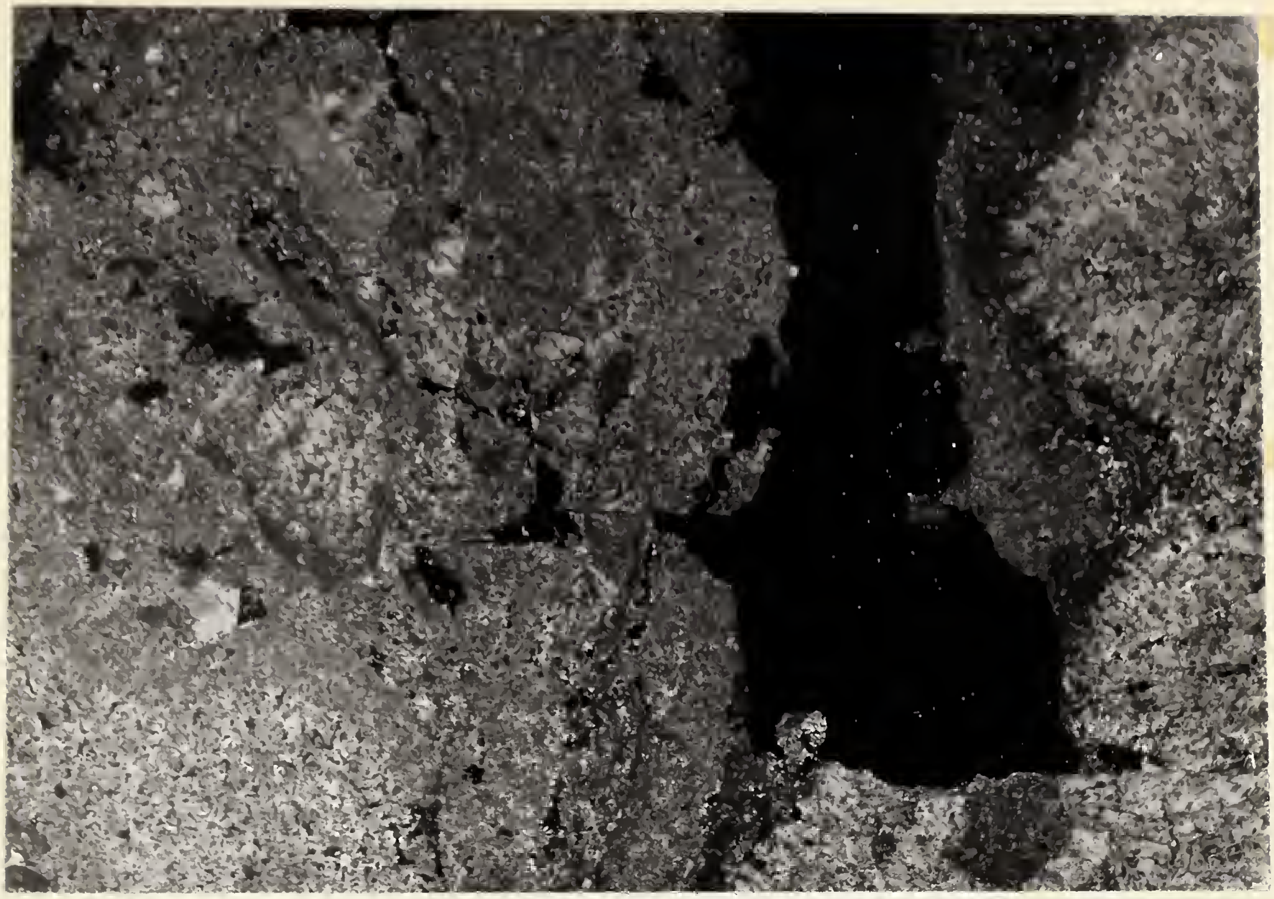
Classification: Bioclastic calcirudite

Thin Section No. 8: Leduc Formation
See Plate 40(a)

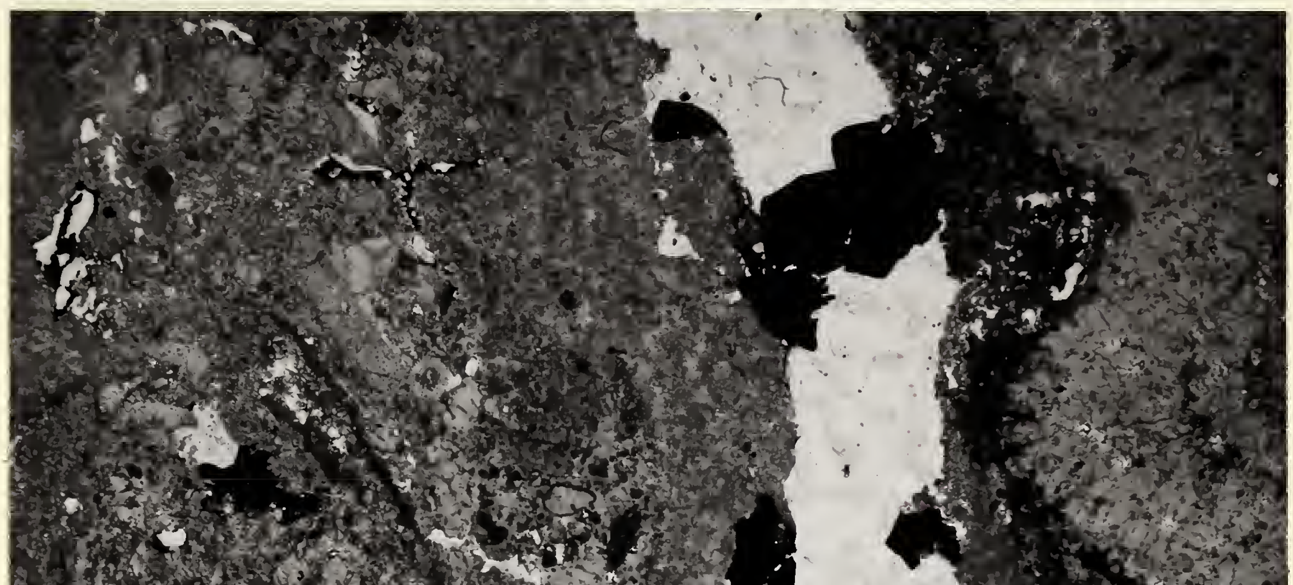
Depth below surface: 4794.7 feet, X10

Description:

Longitudinal section of the tabulate coral *Alveolites* sp. The corallites grow obliquely from different centres of growth and are parallel to the axis of branching. Calcite has developed fibrous texture. Vuggy porosity is present in the corallites. X-ray analysis shows absence of dolomite.

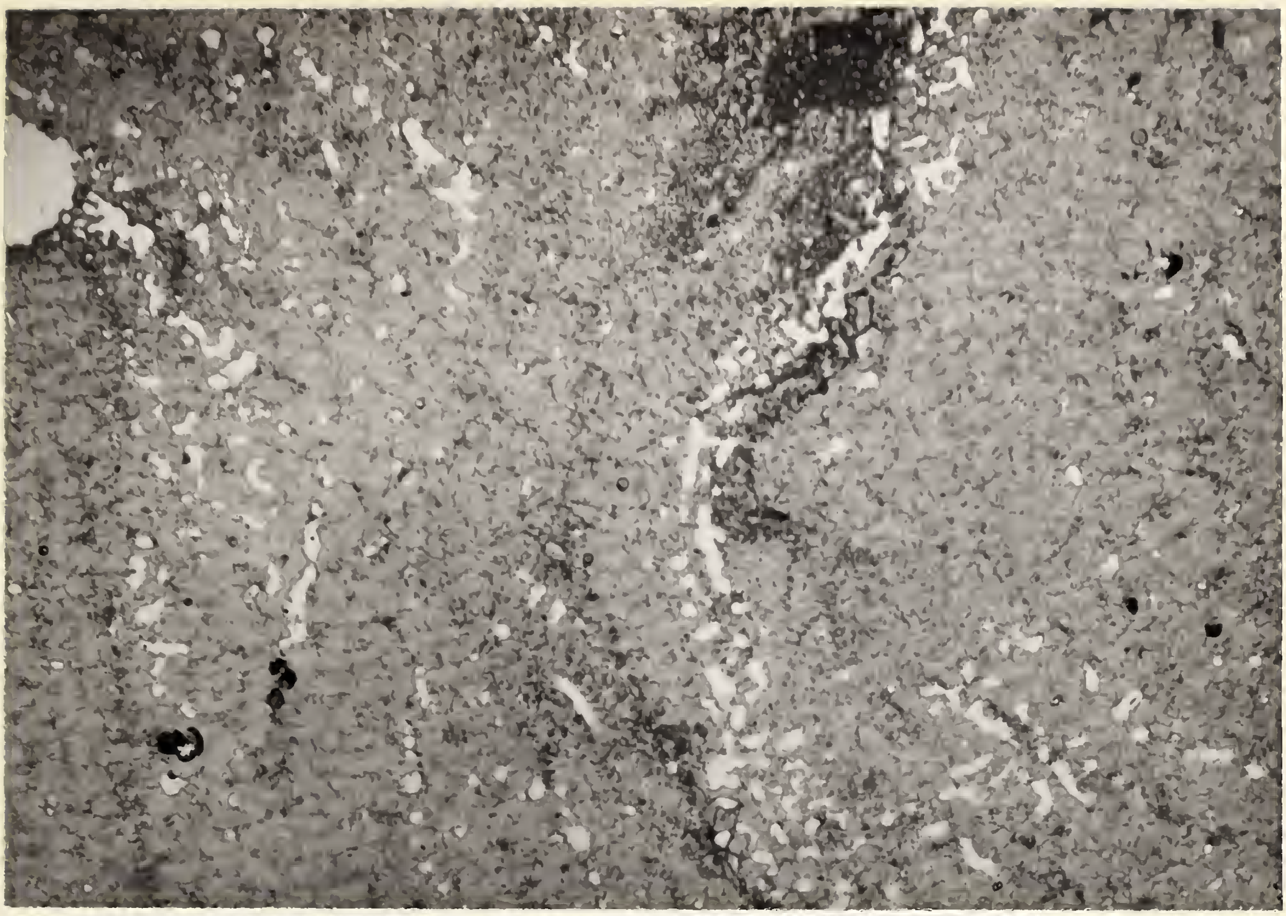


39(b)

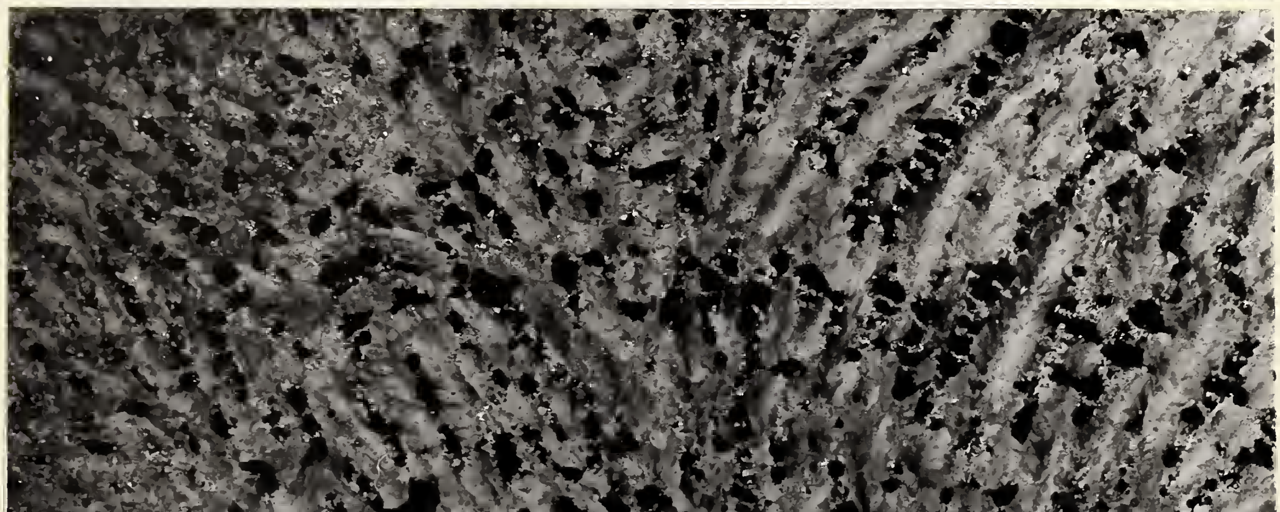


39(a)

Plate 39



40(b)



40(a)

Plate 40

Thin Section No. 9: Leduc Formation
See Plate 40(b)

Depth below surface: 4860 feet, X10

Description:

Longitudinal section of a laminated stromatoporoid exhibiting "pillar-structure". Poor preservation of internal features makes the specific identification rather difficult. The stromatoporoid is composed entirely of calcium carbonate and no dolomitization has taken place (as indicated by X-ray analysis). Calcite has developed fibrous texture. Vuggy porosity is 18 per cent.

Thin Section No. 10: Leduc Formation
See Plate 41(a) and (b)

Depth below surface: 4860 feet, X10

Description:

Fine bioclastic calcirudite matrix is composed of fragments of tabulate corals, algae, stromatoporoids and subangular to subrounded calcite grains. Zoning is common in the calcite grains. The central portion is clouded, whereas the peripheral portion is clear. This is a result of replacement, the central portion representing relict organic structure. In some cases the hexagonal outline of the replaced organisms suggest that they were fragments of tabulate corals.

Larger grains of calcite show incipient cementation around their margins. Rare, isolated euhedral rhombs of dolomite are indicative of incipient dolomitization. However, these are so scarce that X-ray analysis has not detected their presence.

Large fragment of a laminated stromatoporoid with "pillar-structure" is well-exhibited. Inter-fragmental and vuggy porosity is 18 per cent.

Classification: Bioclastic calcirudite

41(b)

41(a)

Plate 41

APPENDIX D

X-Ray Determination of Dolomite-Calcite Ratio

Pure samples of dolomite and calcite were required to establish a standard curve, showing variation in the relative intensities of dolomite_{104} and calcite_{104}. Reconnaissance runs were made on the dolomite and calcite samples before preparing mixtures of known proportion. This was done to ensure that the samples used in making the standard mixtures were pure.

Each sample was first crushed down to very small fragments and then ground manually in an agate mortar. The ground sample was passed through a set of U.S. Standard Sieves and the +140 -230 fraction retained. This powdered sample was placed in an aluminium holder containing a rectangular hole as a sample container, and the dolomite_{104} and calcite_{104} peaks were read for each.

The instrument used was a Norelco X-ray Diffraction unit. X-ray patterns were run using copper radiation with a sodium filter, geiger-counter pick up and the Brown recorder. The instrument was operated at 35 kv. and 15 ma. The 2θ angle for calcite was found to be at 29.4°, and that for dolomite at 31.02°. This insured that the samples were pure and hence suitable for preparing standard mixtures.

These pure, powdered samples of calcite and dolomite were accurately weighed in proportions of 25 per cent dolomite:75 per cent calcite; 50 per cent dolomite:50 per cent calcite; 75 per cent dolomite:25 per cent calcite and 90 per cent dolomite:10 per cent calcite. Each mixture weighed 500 m.gms, which was slightly more than the amount required to fill the hole in the aluminium holder. The two components were mixed together until they acquired homogeneous composition. This was done by grinding them again in an agate mortar in an alcohol medium. The mixture was then dried at room temperature.

To maintain equal quantities in each mount, the same holder was used throughout, and an attempt was made to pack the sample to same density each time. Three mounts were used for each mixture and each mount was run at least thrice. The reproducibility was good as indicated by the slight point scatter on the curve, suggesting a fair precision for the method.

Plotting of Standard Curve

The working curve was constructed after preparing the known mixtures of dolomite and calcite as described above. The $dolomite_{104}/calcite_{104}$ intensity ratio was plotted against percentage dolomite (see Figure 13). The dolomite/calcite ratios were plotted in terms of peak heights, in the units of the standard Norelco graph paper.

The dolomite/calcite ratios for standard mixtures were as follows:

(1) 25% dolomite and 75% calcite

Mount 1	Peak Heights in units 1st run	2nd run	3rd run
Dolomite:	10	6.4	10
Calcite:	22.5	16	23
Ratio (dolomite/calcite):	0.43	0.4	0.44

Average ratio = 0.4

Mount 2	1st run	2nd run	3rd run
Dolomite:	31	31	31
Calcite:	76	77	76
Ratio (dolomite/calcite):	0.4	0.4	0.4

Average ratio = 0.4

Mount 3	1st run	2nd run	3rd run
Dolomite:	27	27	31
Calcite:	69	70	79
Ratio (dolomite/calcite):	0.38	0.38	0.39

Average ratio = 0.4

(2) 50% dolomite and 50% calcite

Peak Heights in units

Mount 1	1st run	2nd run	3rd run
Dolomite:	72	77	81
Calcite:	46	49	51
Ratio (dolomite/calcite):	1.5	1.5	1.5

Average ratio (dolomite/calcite) = 1.5

Mount 2	1st run	2nd run	3rd run
Dolomite:	41	39	36
Calcite:	28	26	28
Ratio (dolomite/calcite):	1.4	1.5	1.3

Average ratio (dolomite/calcite) = 1.4

Mount 3	1st run	2nd run	3rd run
Dolomite:	64	65	55
Calcite:	50	49	42
Ratio (dolomite/calcite):	1.28	1.3	1.3

Average ratio (dolomite/calcite) = 1.3

(3) 75% dolomite and 25% calcite

Mount 1	Peak Heights in units 1st run	2nd run	3rd run
Dolomite:	81	80	79
Calcite:	24	23	24
Ratio ($dolomite_{104}/calcite_{104}$)	3.3	3.4	3.2

Average ratio ($dolomite_{104}/calcite_{104}$) = 3.3

Mount 2	1st run	2nd run	3rd run
Dolomite:	20	21	23
Calcite:	8	6	5
Ratio ($dolomite_{104}/calcite_{104}$)	2.5	3.5	4.6

Average ratio ($dolomite_{104}/calcite_{104}$) = 3.5

Mount 3	1st run	2nd run	3rd run
Dolomite:	70	68	60
Calcite:	20	18	16
Ratio ($dolomite_{104}/calcite_{104}$)	3.5	3.7	3.6

Average ratio ($dolomite_{104}/calcite_{104}$) = 3.6

(4) 90% dolomite and 10% calcite

Mount 1	Peak Heights in units 1st run	2nd run	3rd run	4th run
Dolomite:	29	25	23	18
Calcite:	3	2	2	2
Ratio ($dolomite_{104}/calcite_{104}$)	10	12.5	11.5	9

Average ratio (dolomite/calcite) = 10.7

Mount 2	1st run	2nd run	3rd run
Dolomite:	37	37	36
Calcite:	2.5	2.5	2.5
Ratio ($dolomite_{104}/calcite_{104}$)	14.8	14.8	14

Average ratio ($dolomite_{104}/calcite_{104}$) = 14.5

Mount 3	1st run	2nd run	3rd run
Dolomite:	53.5	53	35
Calcite:	3	3	2
Ratio ($dolomite_{104}/calcite_{104}$)	17.8	17.6	17.5

Average ratio ($dolomite_{104}/calcite_{104}$) = 17.6

TABLE IV

TABULATION OF DOLOMITE/CALCITE RATIOS IN SOCONY DUHAMEL 29-14

IN THE NISKU FORMATION, DUHAMEL AREA, ALBERTA

Sr. No.	Depth below surface in feet	Peak Height		Ratio Dolomite/Calcite	Per cent Dolomite content
		Calcite	Dolomite		
1	4409.7	1	17	17	>90
2	4412.5	1	22	22	>90
3	4415.8	0	18	$\propto$	100
4	4416.2	0	34.5	$\propto$	100
5 (a)	4417.5(shaly)	2	39.5	19.7	>90
(b)	4417.5(reefal)	38.6	46	1.2	50
6	4419.8	1	39	39	>90
7	4422.9	1	39	39	>90
8	4427.8	1.5	37.5	25	>90
9	4432.5	31	9	0.29	15
10	4450.7	0	80	$\propto$	100
11	4462.5	3.5	45.5	1.5	50
12	4473.8	9	32	3.8	75
13	4482.7	0	68	$\propto$	100
14	4488	0	65	$\propto$	100
15	4502.5	0	48	$\propto$	100
16	4514	0	64	$\propto$	100
17	4518.5	0	62	$\propto$	100
18	4522.4	0	74	$\propto$	100
19	4531	0	30	$\propto$	100
20	4535.1	0	39		100

IRETON FORMATION

1	4697.3	0	18	$\propto$	>90

TABLE V

TABULATION OF DOLOMITE/CALCITE RATIOS IN SOCONY DUHAMEL 29-14

IN THE LEDUC FORMATION, DUHAMEL AREA, ALBERTA

Sr. No.	Depth below surface in feet	Nature of sample	Peak calcite	Height dolomite	Dol/Cal ratio	% dolomite
1(a)	4697.5	Matrix	31	15.0	0.48	26
(b)	4697.5	Corals	33	3.0	0.09	2
2(a)	4700	Matrix	39	2.5	0.06	<1
(b)	4700	Stromatoporoids	35	1.0	0.03	<1
3(a)	4706	Matrix	78	1.0	0.01	<1
(b)	4706	Corals	60	1.5	0.02	<1
(c)	4706	Stromatoporoids	39	1.0	0.02	<1
4(a)	4710	Matrix	54	0.0	0.00	0
(b)	4710	Stromatoporoids	44.5	0.0	0.00	0
5(a)	4711.8	Matrix	46	0.0	0.00	0
(b)	4711.8	Corals	48	0.0	0.00	0
(c)	4711.8	Stromatoporoids	55	0.0	0.00	0
6(a)	4714.2	Matrix	46	0.0	0.00	0
(b)	4714.2	Corals	38	0.0	0.00	0
(c)	4714.2	Stromatoporoids	43	0.0	0.00	0
7(a)	4717	Matrix	61	0.0	0.00	0
(b)	4717	Stromatoporoids	40	0.0	0.00	0
8(a)	4724.2	Matrix	38	0.0	0.00	0
(b)	4724.2	Corals	55	3.0	0.05	<1
(c)	4724.2	Stromatoporoids	47	0.0	0.00	0
9(a)	4743	Matrix	22	0.0	0.00	0
(b)	4743	Stromatoporoids	30	0.0	0.00	0
10(a)	4744.5	Matrix	43	0.0	0.00	0
(b)	4744.5	Stromatoporoids	43	0.0	0.00	0

Table V [continued]

Sr. No.	Depth below surface in feet	Nature of sample	Peak calcite	Height dolomite	Dol/Cal ratio	% dolomite
11(a)	4749.7	Matrix	55	0.0	0.00	0
(b)	4749.7	Corals	31	0.0	0.00	0
(c)	4749.7	Stromatoporoids	40	0.0	0.00	0
12(a)	4761.7	Matrix	41	0.0	0.00	0
(b)	4761.7	Stromatoporoids	43	0.0	0.00	0
13(a)	4771	Matrix	71	0.0	0.00	0
(b)	4771	Corals	39	0.0	0.00	0
(c)	4771	Stromatoporoids	48	0.0	0.00	0
14(a)	4773.3	Matrix	42	0.0	0.00	0
(b)	4773.3	Corals	43	0.0	0.00	0
(c)	4773.3	Stromatoporoids	45	0.0	0.00	0
15(a)	4781	Matrix	54	0.0	0.00	0
(b)	4781	Corals	44	0.0	0.00	0
(c)	4781	Stromatoporoids	72	0.0	0.00	0
16	4794.7	Corals	39	0.0	0.00	0
17(a)	4821	Matrix	44	0.0	0.00	0
(b)	4821	Corals	33	0.0	0.00	0
18(a)	4839	Matrix	33	0.0	0.00	0
(b)	4839	Stromatoporoids	35	0.0	0.00	0
19(a)	4848	Matrix	50	0.0	0.00	0
(b)	4848	Stromatoporoids	41	0.0	0.00	0
20(a)	4855.6	Matrix	58	0.0	0.00	0
(b)	4855.6	Stromatoporoids	40	0.0	0.00	0
21(a)	4860	Matrix	49	0.0	0.00	0
(b)	4860	Stromatoporoids	51	3.0	0.06	0

APPENDIX E

X-ray Determination of Strontium Concentration

A reconnaissance run was made on a few of the core samples to determine the presence of strontium and to establish the most sensitive 2θ angle. Two unresolved peaks, the k $_1$ and K $_2$ at 2θ angles of 25.09° and 25.42° were found to be the most sensitive (Powers, 1960).

Preparation of Standard Sample

Pure sample of Iceland spar was ground to 325 mesh grain size in an agate mortar. Weighed amount of the ground calcium carbonate was mixed with a weighed amount of reagent grade strontium nitrate ($Sr(NO_3)_2$ being used as the source for Sr). From this mixture a standard stock sample was made containing 1000 ppm strontium plus an unknown amount of strontium already present in calcium carbonate. By diluting this standard stock sample with weighted amounts of calcium carbonate, mixtures of six different concentrations were prepared (Table VI). These mixtures were made using acetone as a medium to ensure homogeneous mixing.

TABLE VI

Sample No.	*Weight of Standard in gms	Weight of pure calcite in gms	Strontium concentration in ppm	Peak Height
1	0.2	1.8	100	4
2	0.4	1.6	200	6
3	0.6	1.4	300	8
4	0.8	1.2	400	10
5	1.0	1.0	500	12
6	1.4	0.6	700	16
7			1000	22

* The weight of the standard has been doubled in each case to increase the amount of sample.

Sample Calculations

(a) 17 gms of calcite was used to make up a standard stock sample of strontium and calcium carbonate containing 1000 ppm strontium. Strontium nitrate was used as the source of strontium.

Molecular weight of $Sr(NO_3)_2$ = 211.64

Atomic weight of Sr = 87.63

1000 ppm Sr was required in 17 gm of $CaCO_3$

or, 1000 μg strontium per gm $CaCO_3$

Therefore, amount of $Sr(NO_3)_2$ to be added to 17 gms of $CaCO_3$:-

$$17000 \ \mu g \ Sr \times \frac{Sr(NO_3)_2}{Sr}$$

$$17000 \times \frac{211.64}{87.63} = 41050 \ \mu g$$

$$= 41.05 \ mg \ Sr(NO_3)_2$$

That is, 41.05 mg of $Sr(NO_3)_2$ was mixed with 17 gms of calcite to produce a standard sample concentration of 1000 ppm.

(b) Dilution of Standard Sample

$$\text{Concentration of standard} = \frac{\text{wt. of std.} \times \text{conc.} + \text{wt. of pure } CaCO_3}{\text{wt. of std.} + \text{wt. of pure } CaCO_3}$$

$$= \frac{\text{wt. of std.} \times 1000}{1}$$

Example

To prepare 500 ppm concentration, the weight of standard required is:

$$500 = \frac{\text{wt. of std.} \times 1000}{1}$$

Therefore weight of standard - 0.5

The working curve (Figure 17) was then obtained by running the standard samples in X-ray fluorescence unit and plotting the peak heights obtained, against concentration of strontium in ppm. It was found that the straight line obtained by plotting the results did not pass through the zero point of

the graph. This was due to the initial strontium present in the calcium carbonate. Correction for this was made by projecting the standard curve until it cut the abscissa. This point of intersection on the abscissa was regarded as the zero point and all the concentrations were adjusted accordingly.

Preparation of samples

0.5 gms of each sample was weighed and mixed with 2.5 gms of borax. Borax was used as a binder and also as a dilutent to decrease absorption. This mixture was ground in acetone medium in an agate mortar, to a grain size of 325 mesh. The use of acetone during grinding produces a more uniform grain size. A mechanical press (16000 lbs pressure) was used to pack this mixture in shape of a 'disc'. Borax was again used to give it a good packing. The diameter of the disc was about 1 1/4 inch, which is the same as the aluminium holder used for the mounts. Each disc was placed in the sample holder and continually rotated during analysis to increase the homogeneity. This method of preparation and mounting exposed the sample surface directly to the X-rays and also dispensed with the use of a milar window.

The peak heights of each sample were obtained by setting the goniometer of the X-ray unit at an angle $2\theta = 24°$ and allowing it to run to $2\theta = 25°$ at 1°/mt. Each peak was repeated five times and the average peak height calculated. The reproducibility was found to be fairly good. The average peak height was then compared to the standard curve and the strontium concentration determined.

TABLE VII

Strontium Distribution in the Leduc Formation, Duhamel Area, Alberta

Sr. No.	Depth below surface in feet	Nature of Sample	Peak Height	p.p.m. Strontium
1(a)	4697.5	Matrix	4.3	210
(b)	4697.5	Corals	5.0	245
2(a)	4700	Matrix	3.0	148
(b)	4700	Stromatoporoids	3.0	148
3(a)	4706	Matrix	5.0	245
(b)	4706	Stromatoporoids	4.0	200
4(a)	4710	Matrix	4.0	200
(b)	4710	Stromatoporoids	2.9	140
5(a)	4714.2	Matrix	4.4	210
(b)	4714.2	Stromatoporoids	3.5	170
(c)	4714.2	Corals	4.0	200
6(a)	4724.2	Matrix	4.2	205
(b)	4724.2	Corals	3.8	190
7(a)	4743	Matrix	2.5	122
(b)	4743	Stromatoporoids	4.0	200
8(a)	4749.7	Matrix	3.5	170
(b)	4749.7	Stromatoporoids	3.9	195
9(a)	4761.7	Matrix	3.0	148
(b)	4761.7	Stromatoporoids	3.4	165
10(a)	4771	Matrix	2.6	125
(b)	4771	Corals	3.0	148
(c)	4771	Stromatoporoids	3.0	148
11(a)	4781	Matrix	2.8	140
(b)	4781	Corals	3.3	160

Table VII [continued]

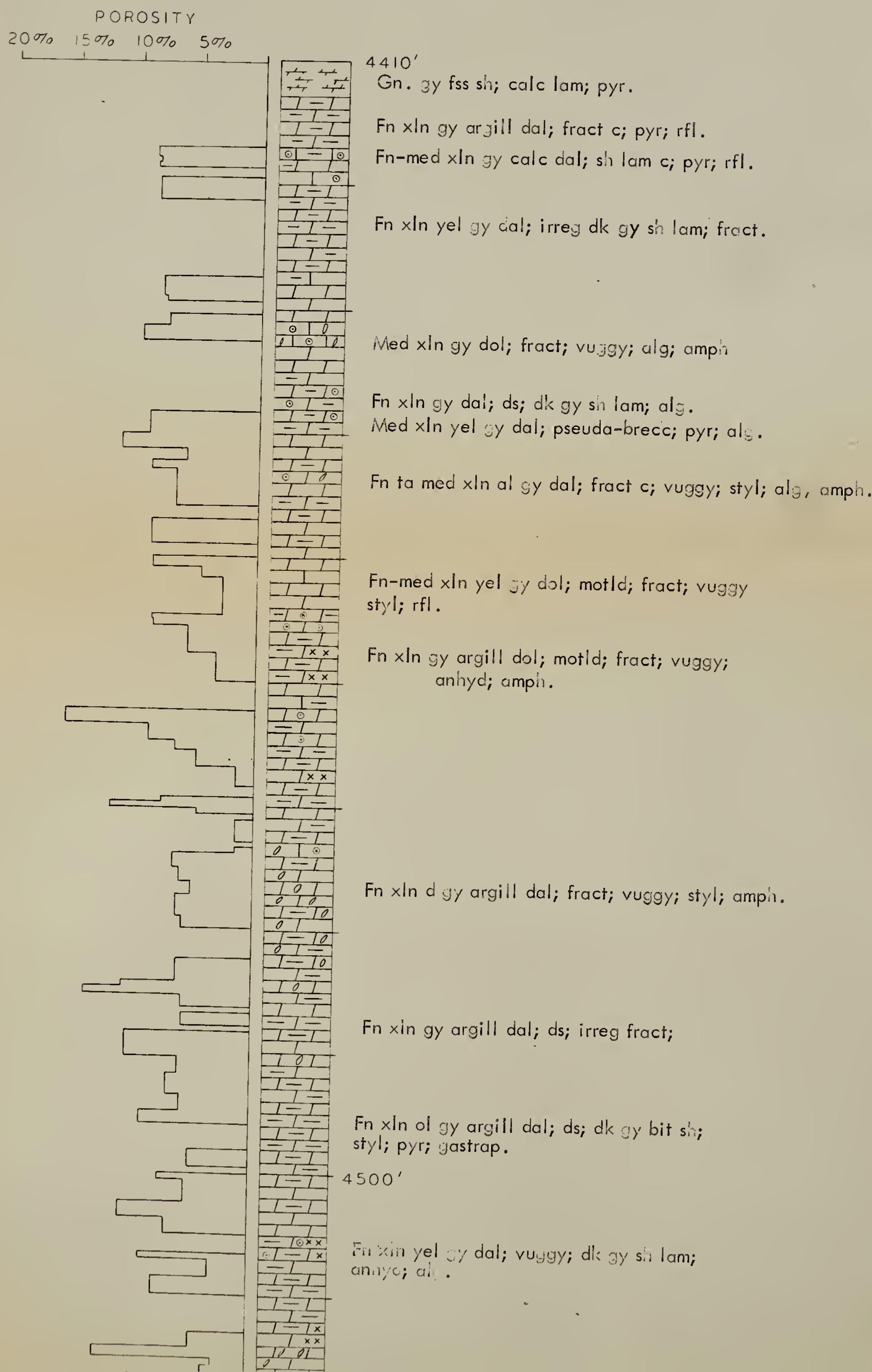
Sr. No.	Depth below surface in feet	Nature of Sample	Peak Height	p.p.m. Strontium
(c)	4781	Stromatoporoids	2.8	140
12	4794.7	Corals	3.0	148
13(a)	4821	Matrix	3.5	170
(b)	4821	Corals	4.0	200
14(a)	4839	Matrix	3.7	182
(b)	4839	Stromatoporoids	3.3	160
15(a)	4848	Matrix	3.0	148
(b)	4848	Stromatoporoids	2.7	130
16(a)	4855.6	Matrix	3.0	148
(b)	4855.6	Stromatoporoids	2.7	130
17(a)	4860	Matrix	3.7	182
(b)	4860	Stromatoporoids	2.8	140
18(a)	4863	Matrix	3.0	148
(b)	4863	Stromatoporoids	3.1	150
19(a)	4868	Matrix	3.0	148
(b)	4868	Corals	2.9	145
(c)	4868	Stromatoporoids	3.3	160

SECTION OF NISKU FORMATION

WELL – SOCONY DUHAMEL NO: 29 – 14

L.S.D. 14-29-45 – 21 – W.4 M.

DEPTH: 4414′ – 4548′



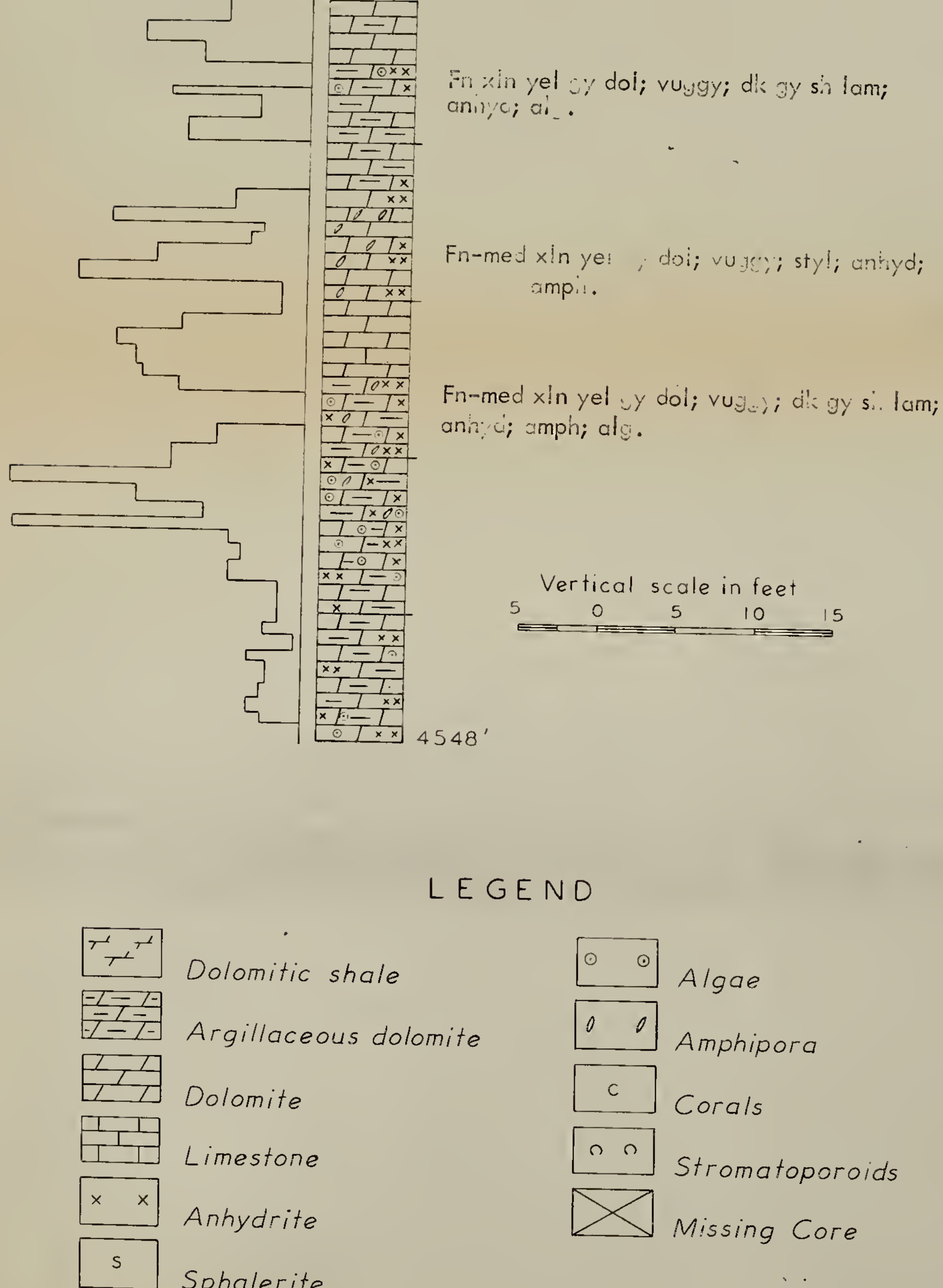

Fn xln yel dol; vuggy; dk gy sh lam;
Fn-med xln yel dol; styl; anhyd;
amph.
Fn-med xln yel dol; dk gy lam;
amph; alg.
4548′
Vertical scale in feet
5 0 5 10 15
LEGEND
Dolomitic shale
Argillaceous dolomite
Dolomite
Limestone
Anhydrite
S
Sphalerite
Algae
Amphipora
C
Corals
Stromatoporoids
Missing Core

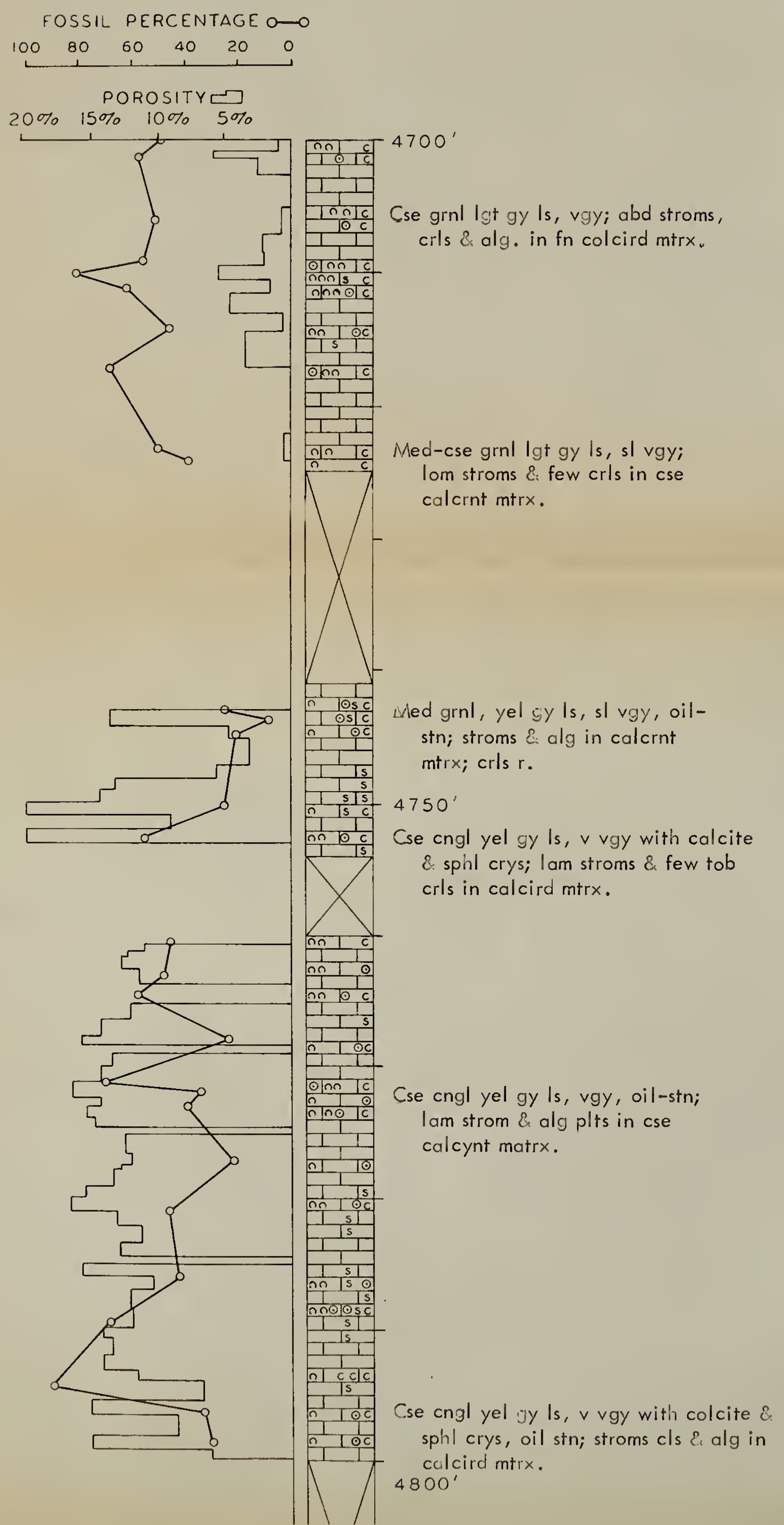
FIG. 20

Section of Leduc Formation

WELL - SOCONY DUHAMEL NO: 29-14

L.S.D. 14-29-45 - 21 - W.4 M

DEPTH: 4700'- 4870'



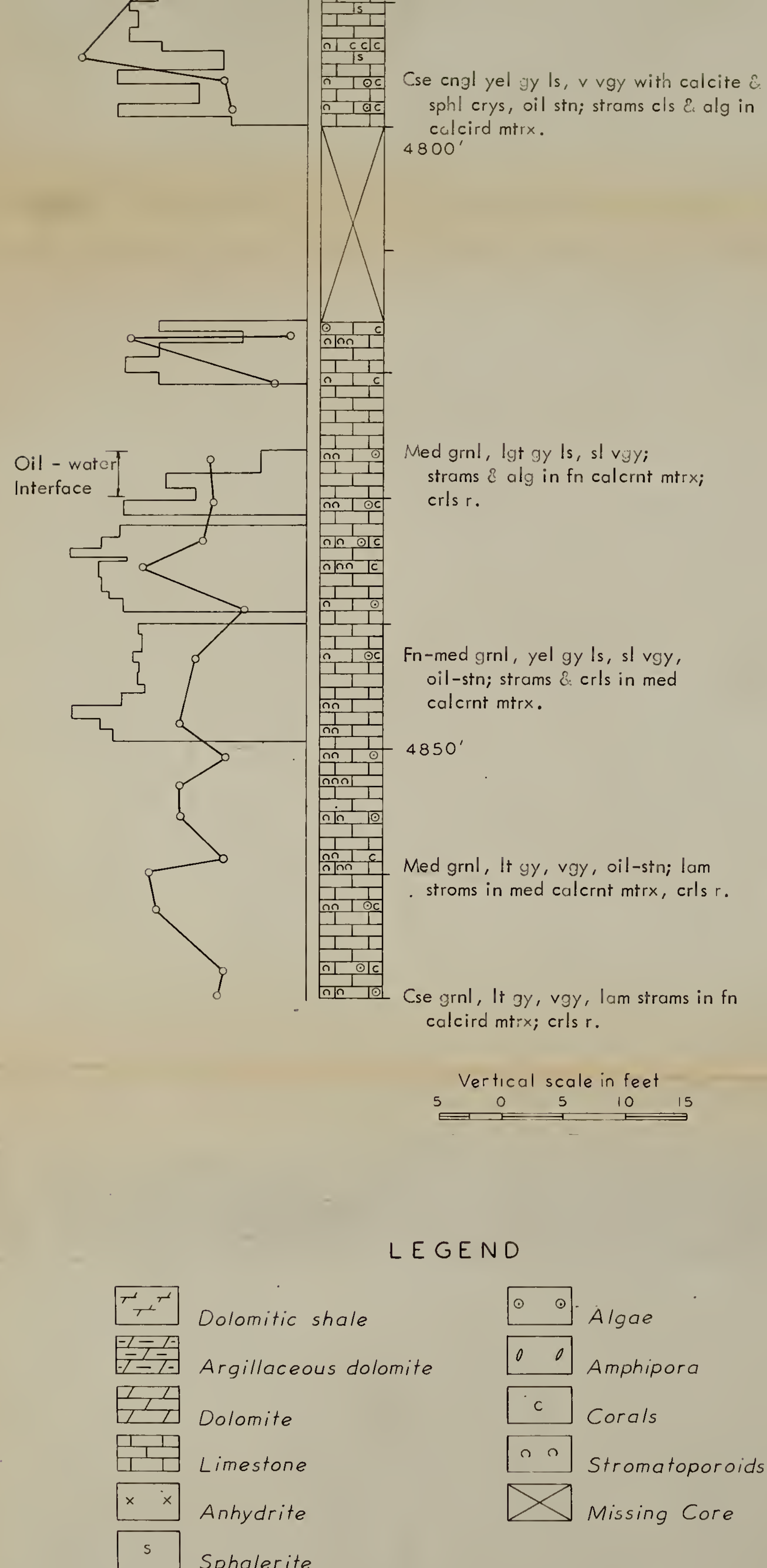

Cse cngl yel gy ls, v vgy with calcite & sphl crys, oil stn; strams cls & alg in calcird mtrx.
4800'
Oil - water Interface
Med grnl, lgt gy ls, sl vgy; strams & alg in fn calcrnt mtrx; crls r.
Fn-med grnl, yel gy ls, sl vgy, oil-stn; strams & crls in med calcrnt mtrx.
4850'
Med grnl, lt gy, vgy, oil-stn; lam stroms in med calcrnt mtrx, crls r.
Cse grnl, lt gy, vgy, lam strams in fn calcird mtrx; crls r.
Vertical scale in feet
5 0 5 10 15
LEGEND
Dolomitic shale
Argillaceous dolomite
Dolomite
Limestone
Anhydrite
Sphalerite
Algae
Amphipora
Corals
Stromatoporoids
Missing Core

FIG. 21